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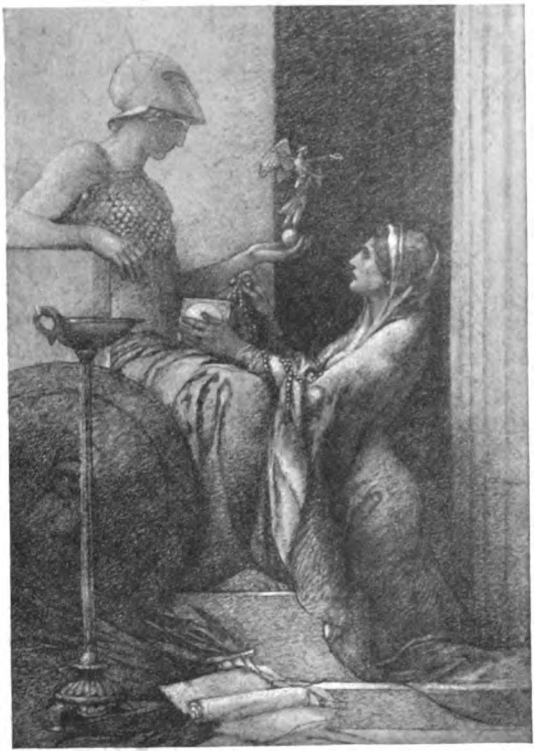

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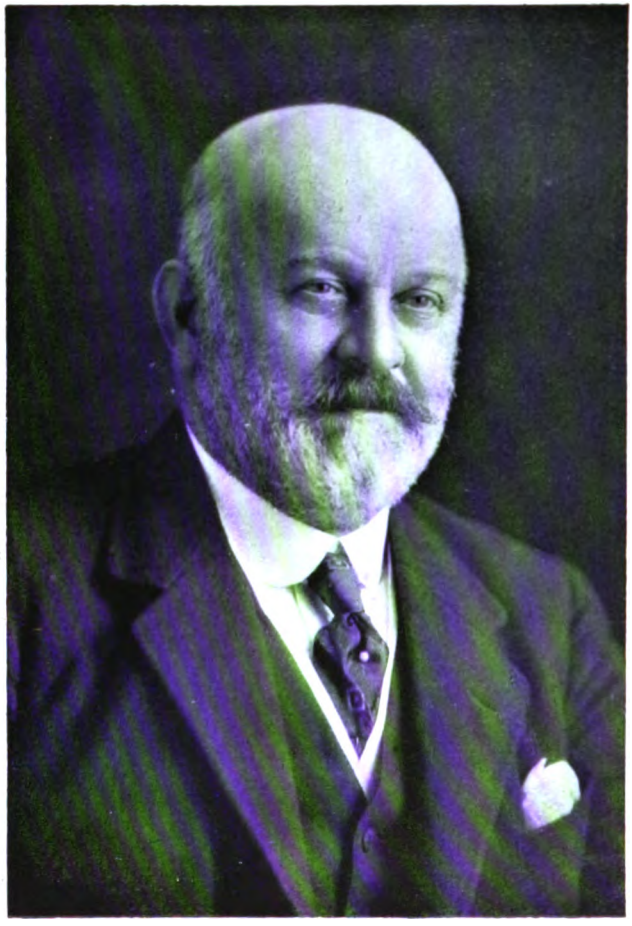

Yours sincerely,

A. J. Campbell

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TRANSACTIONS

OF THE

Institution of Engineers and Shipbuilders

IN SCOTLAND

(INCORPORATED).

VOLUME LXIX.

SIXTY-NINTH SESSION, 1925-26.

EDITED BY THE SECRETARY.

GLASGOW:
PUBLISHED BY THE INSTITUTION AT
39 ELMBANK CRESCENT.

1926

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A. J. Campbell

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1911-13 EBENEZER HALL-BROWN, Marine Engineer, Glasgow.

1913-15 ROBERT THOMAS MOORE, D.Sc., Civil and Mining Engineer, Glasgow.

1915-17 W. W. LACKIE, C.B.E., Engineer and Manager, Glasgow Corporation Electricity Works.

1917-19 ALEXANDER CLEGHORN, Marine Engineer, Glasgow.

1919-21 THOMAS BLACKWOOD MURRAY, D.Sc., Automobile Engineer, Glasgow.

1921-23 HAROLD E. YARROW, C.B.E., Engineer and Shipbuilder, Glasgow.

1923-25 J. HOWDEN HUME, Marine Engineer, Glasgow.

1925-26 ARCHIBALD JACK CAMPBELL, Shipbuilder, Dalmuir.

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ADVERTISEMENT.

The responsibility for the statements and opinions given in the following Papers and Discussions rests with the individual authors; the Institution as a body merely places them on record.

ERRATA.

Page 210. Under "Details of Main Engines." Diameter of Cylinders, read 58 instead of 18 inches.

Page 269. Line 16 from top, read 15,300 instead of 29,700 B.Th.U's./lbs.

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MEMORANDUM OF ASSOCIATION

OF THE

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

---

1. The Name of the Association is "THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND."

2. The Registered Office of the Association will be situate in Scotland.

3. The Objects for which the Association is established are: -

(1) The Incorporation of the present Institution of Engineers and Shipbuilders in Scotland, under the 30th and 31st Victoria, cap. cxxxi., and

(2) To facilitate the exchange of information and ideas amongst its Members, to place on record the results of experience elicited in discussion, and to promote the advancement of science and practice in Engineering and Shipbuilding.

(3) The doing all such other lawful things as are incidental or conducive to the attainments of the above objects.

4. The Income and Property of the Association, whencesoever derived, shall be applied solely towards the promotion of the objects of the Association, as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever, by way of profit, to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them.

Provided that nothing herein shall prevent the payment in good faith of remuneration to any Officers or Servants of the Association or to any Member of the Association, or other person, in return for any services rendered to the Association.

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5. The fourth paragraph of this Memorandum is a condition on which a Licence is granted by the Board of Trade to the Association, in pursuance of Section 23 of the "Companies Act, 1867." For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which may be duly observed by the Association.

6. If the Association acts in contravention of the fourth paragraph of this Memorandum, or of any such further Conditions, the liability of every Member of the Council of the Association, and also of every Member who has received any such dividend, bonus, or other profit as aforesaid, shall be unlimited.

7. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the Debts and Liabilities of the Association, contracted before the time at which he ceases to be a Member, and of the Costs, Charges, and Expenses of winding up the same, and for the adjustment of the rights of the Contributaries among themselves—such amount as may be required, not exceeding Ten Pounds, or, in case of his liability becoming unlimited, such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

WE, the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association:—

Names, Addresses, and Description of Subscribers—

DAVID ROWAN, 217 Elliot Street, Glasgow, Engineer.
W. J. MACQUORN RANKINE, C.E., LL.D., etc., 59 St. Vincent St., Glasgow.
M. R. COSTELLOE, 25 Granville Street, Glasgow, Measuring Surveyor.
BENJAMIN CONNOR, 17 Scott Street, Garnethill, Engineer.
JAMES DEAS, 16 Robertson Street, Glasgow, Civil Engineer.
JAMES M. GALE, 23 Miller Street, Glasgow, Civil Engineer.
W. MONTGOMERIE NEILSON, C.E., Hyde Park Locomotive Works, Glasgow.

Dated the Twelfth day of July, Eighteen Hundred and Seventy-One.

ROBERT ROSS, of Glasgow, Solicitor, Witness to the above signatures.

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NOTE.—By Special Resolution passed on 2nd October, 1902, and confirmed on 20th October, 1902, the Articles of Association dated 12th July, 1871, as modified and altered in 1873 and 1880, were annulled, and the following Articles of Association (with the exception of Articles Nos. 23, 25, and 27) were substituted, and they were registered with the Registrar of Joint-Stock Companies on 28th October, 1902.

By Special Resolution passed on 20th March, 1906, and confirmed on 17th April, 1906 the Articles Nos. 23, 25, and 27 of the Articles registered on 28th October, 1902, were cancelled, and the Articles Nos. 23, 25, and 27 below were substituted. This Resolution was lodged with the Registrar of Joint-Stock Companies on 28th April, 1906.

By Special Resolutions passed on 30th March, 1920, and confirmed on 20th April, 1920, the Articles Nos. 46 and 48 of the Articles registered on 28th October, 1902, were cancelled, and the Articles Nos. 46 and 48 below were substituted. These Resolutions were lodged with the Registrar of Joint-Stock Companies on 30th April, 1920.

ARTICLES OF ASSOCIATION

OF THE

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

SECTION I.—PRELIMINARY.

1. For the purpose of registration, the number of Members of the Institution is declared unlimited.

2. These Articles shall be construed with reference to the provisions of the Companies Acts, 1862 to 1900; and terms used in these Articles shall be taken as having the same respective meanings as they have when used in those Acts.

3. The Objects of the Institution are those set forth in the Memorandum of Association. Objects of the Institution.

SECTION II.- CONSTITUTION.

4. The Institution shall consist of Members, Associate Members, Associates, Students, and Honorary Members. Constitution.

5. Candidates for admission as Members shall be persons not under 25 years of age, who have been educated as Engineers or Shipbuilders and have occupied a responsible position in connection with the Practice or Science of Engineering or Shipbuilding. Who may be Members.

6. Candidates for admission as Associate Members shall be persons not under 22 years of age, who have Who may be Associate Members.

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been educated as Engineers or Shipbuilders and are engaged in the Practice or Science of Engineering or Shipbuilding

Who may be Associates.

7. Candidates for admission as Associates shall be such persons, not included in the classes enumerated in the two preceding Articles, who, not being under 25 years of age are considered by the Council eligible on account of their scientific attainments, or are considered by the Council qualified by knowledge bearing on Engineering Science or Practice.

Who may be Students

8. Candidates for admission as Students shall be persons not under 18 years of age who are engaged in study or employment with a view to qualifying themselves as Engineers or Shipbuilders. Before attaining the age of 25 years they must apply for election as Members or Associate Members if they desire to remain connected with the Institution. They may not continue to be Students after attaining the age of 25 years.

Who may be Hon. Members.

9. Honorary Members shall be such distinguished persons as the Council shall recommend and the Institution shall appoint. The number of Honorary Members shall not exceed Twelve.

Members, etc., under former Articles of Association.

10. All persons whose names shall on 30th April, 1902, be on the Roll of the Institution under the former Articles of Association as Members, Associates, or Honorary Members, and whose subscriptions are not more than two years in arrear at that date, shall become Members, Associates, and Honorary Members respectively within the meaning of these Articles, and that without procedure of any kind on the part of such persons.

Graduates under former Articles of Association

11. All persons whose names shall on 30th April, 1902, be on the Roll of the Institution under the former Articles of Association as Graduates, and whose subscriptions are not more than two years in arrear at that date, shall be considered and treated as Students within the meaning of these Articles,

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and shall have the privileges, and be subject to the regulations affecting Students; and, notwithstanding the terms of Article 8 hereof, such Graduates as are over 25 years of age shall be allowed to remain as Students for one year from and after 30th April, 1902, but no longer.

Abbreviated Titles of Members, etc.

12. The abbreviated distinctive titles for indicating the connection with the Institution shall be the following, viz.—For Members, M.I.E.S.; for Associate Members, A.M.I.E.S.; for Associates, A.I.E.S.; for Students, S.I.E.S.; and for Honorary Members, Hon. M.I.E.S.

Candidates, how recommended and elected.

13. Every Candidate for admission as a Member, Associate Member, Associate, or Student of the Institution, shall obtain the recommendation of at least three Members, such recommendation and the relative undertaking by the Candidate being according to Form A contained in the Appendix. Such recommendation and undertaking shall be lodged with the Secretary, and the Council shall consider the same at their first meeting thereafter, and if they approve the recommendation shall be mentioned in the notice calling the next General Meeting of the Institution; and then, unless a ballot be demanded by at least five persons entitled to vote, the Candidate shall be declared elected. If a ballot be taken he shall be admitted if three-fifths of the votes are favourable; Members only being entitled to vote. The proposal for transferring any person from the Class of Students to the Classes of Associate Members or Members, or from the Class of Associate Members to the Class of Members, shall be according to Form B contained in the Appendix, and this form shall be subscribed by at least three Members and delivered to the Secretary for the consideration of the Council who shall, if they think fit, make the proposed transfer.

14. The granting of Honorary Membership to

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Honorary Members, how elected.

any person may be proposed at any Council meeting, and, if the Council, after consideration at their next meeting, approve of the proposal, intimation thereof shall be given by the Secretary in the circular calling the next General Meeting of the Institution. At that meeting, unless a ballot be demanded by at least five persons entitled to vote, the person proposed shall be declared elected. If a ballot be taken then the person proposed shall be admitted if four-fifths of the votes are favourable; Members only being entitled to vote.

Members, etc., formally admitted.

15. Every person duly elected or admitted as a Member, Associate Member, Associate, Student, or Honorary Member shall be notified in writing of his election or admission by the Secretary. At the first meeting of the Institution held thereafter at which he is present, he shall be introduced according to the ensuing form, viz.—The President or the Chairman of the meeting, addressing him by name, shall say: "As President (or Chairman of this meeting) of the Institution of Engineers and Shipbuilders in Scotland, I introduce you as a Member (or Associate Member or Associate or Student or Honorary Member as the case may be)." Thereafter the New Member, Associate Member, Associate, Student, or Honorary Member shall sign the Roll of Members, etc, to be kept by the Secretary, and on making payment of any fees or subscriptions due he shall be entitled to receive a diploma. The diploma shall be signed by the President and the Secretary.

Diploma.

Rejected candidates not to be noticed in Minutes—wish of Honorary Members to be obtained before being balloted for.

16. If any person proposed for admission into the Institution be not approved by the Council, or be rejected on being balloted for, no notice shall be taken of the proposal in the Minutes of the General Meetings, and such person shall not be proposed again for admission until after the expiry of one year from the date of such disapproval or rejection. Before the meeting of Council for considering any

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proposal to grant Honorary Membership, it shall be ascertained from any person proposed to be made an Honorary Member whether he will accept the honour, no notice being taken of the proposal in the Minutes unless he is elected.

Section III. MANAGEMENT AND OFFICE-BEARERS.

Council, Management by.

17. The Direction and Management of the affairs of the Institution shall be confided to a Council, which shall consist of a President, six Vice-Presidents, and eighteen Councillors. Of the eighteen Councillors, not more than three may be Associates, the remainder being Members. Five Members of Council shall constitute a quorum.

Constitution of Council—five a quorum

Who may be President.

18. Members only shall be eligible for election as President. The President shall preside over all meetings of the Institution and Council at which he is present, and shall regulate and keep order in the proceedings. The President shall hold office for one year only, but shall be eligible for re-election at the expiry of the year.

Who may be Vice-Presidents

19. Members only shall be eligible for election as Vice-Presidents. In the absence of the President, the Vice-Presidents in rotation shall preside at meetings of the Council and Institution. The Vice-Presidents shall hold office for three years.

Chairman to have casting vote.

20. In case of the absence of the President and all the Vice-Presidents, the meeting may elect any one of the Council, or any Member, to preside. In all cases the Chairman of any meeting shall have a Deliberative Vote and a Casting Vote.

Who may be Councillors.

21. Members and Associates only shall be eligible for election as Ordinary Members of Council, and shall hold office for three years, and not more than three Associates shall hold office in the Council at any one time.

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22. Past Presidents of the Institution shall be *ex officio* Honorary Members of Council.

First Council.

23. The Office-Bearers in office at 30th April, 1902, shall continue in office till the first General Meeting of the Institution in October, 1902, when a new Council shall be elected in terms of these Articles. Such Office-Bearers shall be eligible for election for the new Council. Of the new Council, two Vice-Presidents shall retire in October of each of the years 1903, 1904, and 1905, their places being filled by election, and the persons elected shall hold office until the expiry of the terms of office. Similarly of the new Council, six Councillors (being five Members and one Associate) shall retire in October, 1903, and a like number in October, 1904, and the remainder in October, 1905, their places being filled by election at these dates respectively, and their successors retiring at the expiry of the terms of office, and so on thereafter, from year to year. The Vice-Presidents to retire in October, 1903 and 1904, shall be determined by lot among the six Vice-Presidents first elected, and the Members of Council to retire in October, 1903 and 1904, shall be determined by lot among the Members of Council first elected. The Vice-Presidents and the Ordinary Members of Council who fail to retire at the dates mentioned, or who fail to retire at any time on the expiry of their term of office, shall not be eligible for re-election in the same capacity, nor shall a retiring Vice-President be eligible for election as a Member of Council until one year has elapsed from the date of retiral.

Retiral of Members of Council.

Office-Bearers to be elected by Ballot.

24. The Members of Council shall be elected by ballot at the Annual General Meeting, such meeting being the last Ordinary Meeting held in each month of April, but the new Office-Bearers elected at this meeting shall not enter office until 1st October following. In the election of President, Vice-Presidents, and Ordinary Members of Council from the

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Class of Associates, all Members, Associate Members, and Associates shall be entitled to vote. In the election of the other Members of Council only Members and Associate Members shall be entitled to vote.

Lists for Election.

25. In March of each year the Council shall meet and prepare a list of names for the election of Council for the ensuing year. This list shall be submitted to the Members at the Monthly Meeting preceding the Annual Meeting, and the Members present may, by motion, duly seconded, propose any additional names for any of the offices.

Ballot Lists to be sent to Members.

26. Fourteen days before the General Meeting in April of each year the list as proposed by the Council for the election of Members and others to fill the vacancies in the Council for the ensuing year, with such additions as may have been made thereto under Article 25, shall be printed and sent to all Members and Associate Members, and the list shall serve as a ballot paper. A similar list shall be printed and sent to all Associates containing the names of those for whom they are entitled to vote. Those persons entitled to vote may vote for as many names on the list as there are vacancies to be filled. In the event of any ballot paper not containing names equal to the number of vacancies to be filled, such ballot paper shall be treated as a spoiled paper.

The ballot papers may be sent by post or otherwise to the Secretary, so as to reach him before the day and hour named for the Annual General Meeting, or they may be presented personally by those entitled to vote, at the opening of the meeting.

Vacancies occurring during the Session to be filled up by the Council.

27. A vacancy occurring during any Session in consequence of the resignation or death of any Office-Bearer (except the President) shall be filled up by the Council, until the next Annual General Meeting for electing Office-Bearers. Any vacancy in the office of President shall be filled up at the next General Meeting of the Institution. A person

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elected to fill a vacancy shall hold office for the period unexpired of the term of office of the Office-Bearer resigning or dying or being removed from office, and he shall not be eligible for re-election.

SECTION IV.—POWERS AND DUTIES OF COUNCIL.

Meetings of Council.

28. The Council shall meet as often as the business of the Institution requires, and during each Session—that is, from October till April—the Council shall meet at least once a month.

Committees.

29. The Council may delegate any of their powers to Committees consisting of such Members of the Council as they think fit, and they may appoint Committees to report to them upon special subjects. In particular, they shall appoint a Finance Committee to superintend the finances of the Institution, a Library Committee to superintend Library arrangements, and a Papers Committee to arrange for papers being submitted at meetings of the Institution. The Minutes of all Committees shall not take effect until approved by the Council. The President shall be *ex officio* a Member of all Committees.

Honorary Treasurer.

The Convener of the Finance Committee shall be styled Honorary Treasurer. He shall be elected by the Council from their number, and notwithstanding the provision for retiral in Article 23, he shall be entitled to retain the office of Honorary Treasurer for three years from the date of his appointment.

Bye-laws, etc.

30. The Council may make Bye-Laws and Regulations for carrying on the business of the Institution, and, from time to time, alter, amend, repeal, vary, or add to the same; but any Bye-Law or Regulation, or any alteration or amendment thereon, or addition thereto, shall only come into force after the same has been confirmed at a General Meeting of the Institution, and no Bye-Law or Regulation shall be made under the foregoing which would amount to

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such an addition to or alteration of these Articles as would only be legally made by a Special Resolution passed and confirmed in accordance with Sections 50 and 51 of the Companies Act, 1862. The Council shall be entitled to invest the Funds of the Institution as they think fit, on such security, heritable or moveable, as to them shall seem proper, and may alter or vary the investments from time to time. The Council may purchase or sell property, heritable or moveable, for the use of the Institution, and may borrow money on the security of the property of the Institution, subject to confirmation by the Institution at an Extraordinary Meeting called for the purpose.

Investments.

Council may purchase or sell.

Borrowing.

31. The Council shall appoint a Secretary and a Treasurer, and any other official or servant required to carry on the work of the Institution, and the appointments made by the Council shall be on such terms and conditions as the Council may think fit.

Officials appointed.

32. All questions in or before the Council shall be decided by vote, and such vote shall be taken by a show of hands or by ballot; but at the desire of any four Members present the determination of any subject shall be postponed till the next meeting of Council.

Votes at Council Meetings.

Section V.—SECRETARY AND TREASURER.

33. Subject to Regulations by the Council, the Secretary (who may also act as Treasurer) shall conduct the correspondence of the Institution; attend all meetings of the Institution, of the Council, and of Committees; take Minutes of the proceedings of such meetings, and enter them in the proper books provided for the purpose; read at all meetings of the Institution and Council respectively the Minute of the preceding meeting, and all communications received by him or ordered to be read; superintend the publication of such papers as the Council may direct; take charge of the Library; issue notices of meetings; issue diplomas; keep the Roll and Regis-

Duties of Secretary.

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ters; and perform whatever other duties are indicated in the Regulations of the Institution as appertaining to his department or set forth in the terms of his appointment.

Duties of Treasurer.

34. Subject to regulation by the Council, the duties of the Treasurer shall be to take charge of the property of the Institution (excepting books, papers, drawings, models, and specimens of materials, which shall be in charge of the Secretary); to receive all payments and subscriptions due to the Institution; to direct the collection of subscriptions; to pay into one of the Glasgow Banks, in the joint names of the President, Honorary Treasurer, and himself, the cash in his hands whenever it shall amount to Ten Pounds; to pay all sums due by the Institution, but not without an order signed by two Members of the Finance Committee, and to keep an account of all his intromissions in the General Cash Book of the Institution, which shall upon all occasions be open to inspection of the Finance Committee, and which shall be balanced annually, as at 30th September. The Treasurer shall prepare an Annual Statement of the Funds of the Institution, and of the receipts and payments of each financial year, which shall be audited by the Auditor aftermentioned, and this Statement of the Funds and an Inventory of all the property possessed by the Institution, and a List of the Members, Associate Members, Associates, and Students whose subscriptions are in arrear, shall be submitted to the First Meeting of the Council, in October.

Annual Report.

35. An Annual Report upon the affairs of the Institution shall be drawn up under the direction of the Council at a meeting to be held not less than ten days before the General Meeting of the Institution in October. This report shall embody reports from the representatives elected by the Council to various official bodies.

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SECTION VI.—AUDIT OF ACCOUNTS.

Auditor and duties.

36. An Auditor, who must be a Chartered Accountant of at least five years standing, shall be appointed by the Council at their meeting preceding the last General Meeting of each Session, to examine the accounts and books of the Treasurer, and the Annual Financial Statement or Statements of the Funds, and that Statement, along with the Audit and Annual Report, shall be printed in the notice calling the First General Meeting of the Institution in October, and shall be read at that meeting.

SECTION VII.—MEETINGS AND PROCEEDINGS OF THE INSTITUTION.

Ordinary General Meetings every four weeks during the Session.

37. The Institution shall hold ordinary meetings for reading papers, and for discussing matters connected with the objects of the Institution; and such meetings shall take place regularly, at least once in every four weeks during each Session; and may be adjourned from time to time. The Sessions shall commence in October, and continue until the month of April next following, inclusive. No business shall be transacted at any meeting unless 25 Members shall be present.

At the General Meeting in April of each year for the election of Office-Bearers, the order of business shall be:—

(1) Minutes of last meeting.
(2) To read and consider the reports of the Council and Treasurer.
(3) The meeting shall nominate two Scrutineers, who shall be Members, and shall hand to them the ballot-box containing the voting papers for the new Office-Bearers.
(4) The Scrutineers shall receive all ballot papers which may have reached the Secretary, and all others which may be pre-

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sented at the meeting. The Scrutineers shall then retire and verify the lists and count the votes, and shall, before the close of the meeting, report to the Chairman the names which have obtained the greatest number of votes subject to the conditions of the ballot. The Chairman shall then read the list presented by the Scrutineers, and shall declare the gentlemen named in the list to be duly elected, provided always that the list does not contain more names than there are vacancies to be filled.

Ordinary Meetings—order of business.

38. At every ordinary meeting of the Institution, the Secretary shall first read the Minutes of the preceding meeting, which, on approval, shall then be signed by the Chairman of the meeting at which the Minutes are read and approved. The Secretary shall next read any notices which may have to be brought before the meeting; after which any Candidates for admission may, if necessary, be balloted for, and any new Members shall be admitted. Any business of the Institution shall then be disposed of, after which notices of motion may be given. The paper or papers for the evening shall then be read and discussed. Each Member shall have the privilege of introducing one friend to the General Meetings, whose name must be written in the Visitors' Book, together with that of the Member introducing him; but if the introducing Member be unable to attend the meeting, he may send with the visitor a card signed by him addressed to the Secretary. During such portions of any of these meetings as may be devoted to any business connected with the management of the Institution, visitors may be requested by the Chairman to withdraw.

Nature of papers to be read.

39. All papers read at the meetings of the Institution must be connected with the Science or Prac-

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tice of Engineering or Shipbuilding, and must be accepted by the Papers Committee before being read

Proceedings to be published.

40. The papers read, and the discussions held during each Session, or such portion of them as the Council shall select, shall be printed and published forthwith.

Explanatory notes after reading of papers may be published

41. Explanatory notes communicated after the reading or discussing of papers may be printed in the *Transactions*, if the Council see fit.

Copyright of papers shall be the property of the Institution.

42. The copyright of any paper read at a meeting of the Institution with its illustrations, shall be the exclusive property of the Institution, unless the publication thereof by the Institution is delayed beyond the commencement of the Session immediately following that during which it is read; in which case the copyright shall revert to the author of the paper. The Council shall have power, however, to make any arrangement they think proper with an author on first accepting his paper.

Members, etc., to receive copies of *Transactions*— Authors 30 copies of their papers.

43. The printed *Transactions* of each Session of the Institution shall be distributed gratuitously, as soon as ready, to those who shall have been Members, Associate Members, Associates, or Honorary Members of the Institution during such Session, and they shall be sold to the public at such prices as the Council shall fix. Authors of papers shall be entitled to thirty separate copies of their papers, with the discussions, as printed in the *Transactions*.

Special Meeting may be called by the Council or on requisition by 25 Members.

44. Extraordinary or Special Meetings may be called by the Council when they consider it proper or necessary, and must be called by them on receipt of a requisition from any 25 Members, specifying the business to be brought before such meeting.

Voting.

45. Any question which, in the opinion of the President or the Chairman of the meeting of Council and Institution, is of a personal nature shall be decided by ballot; all other questions shall be decided by a show of hands, or by any convenient system of

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Who may vote.

open voting. In all cases, not hereinbefore provided for, only Members, Associate Members, and Associates shall be entitled to vote. Every Member, Associate Member, and Associate shall have one vote only, which must be given personally.

Section VIII.—SUBSCRIPTIONS OF MEMBERS AND OTHERS.

Annual Subscription payable.

46. Each Member shall, on election, pay an Entrance Fee of £1, and for the current and for each Session thereafter an Annual Subscription of £3.

Each Associate Member shall, on election, pay an Entrance Fee of £1, and for the current Session and each of the two following Sessions an Annual Subscription of £1 10s., and thereafter an Annual Subscription of £2 5s.

Each Associate shall, on election, pay an Entrance Fee of £1, and for the current Session and each Session thereafter an Annual Subscription of £2 5s.

Each Student shall pay an Annual Subscription of Fifteen Shillings, but no Entrance Fee.

In the case of Members, Associate Members, Associates, and Students, elected during March and April, no subscription shall be payable for the current Session.

47. Honorary Members shall be liable for no contribution or subscription or Entrance Fee.

48. The liability of any Member or Associate for future Annual Subscriptions may be commuted by the following payments—viz., in the case of a Member, by the payment of £40; and in the case of an Associate by the payment of £30, and, in the event of such payment being made by a Member or Associate on his admission to the Institution, the same shall be in full of Entry Money as well as future Annual Subscriptions.

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49. All persons transferred, in terms of Articles 10 and 11, to the Roll of Members, Associates, or Students, to be kept under these Articles, shall not be liable to pay any Entrance Fee, but for the Session 1902-3, and thereafter, they shall be liable for the Annual Subscription applicable to the Class to which they are transferred. All persons who, as Members or Associates under the former Articles of Association, had commuted their Annual Subscriptions by a capital payment to the Institution shall not be liable for any subscription, notwithstanding the terms of this Article.

When Annual Subscriptions due.

50. Annual Subscriptions shall become due on the first day of October in each year, and must be paid before 1st January following.

Members, etc., not entitled to vote if in arrear.

51. No Member or Associate Member or Associate whose subscription is in arrear shall be entitled to vote at any meeting of the Institution nor to receive copies of papers or proceedings while the subscription remains unpaid.

52. Any Member, Associate Member, Associate, or Student whose subscription is more than three months in arrear shall be notified by the Secretary. Should his subscription become six months in arrear he shall be again notified by the Secretary, and all his rights in connection with the Institution shall be suspended. Should his subscription become one year in arrear he shall be removed from the Roll of the Institution unless the Council may deem it expedient to extend the time for payment.

Members, etc., retiring from the Institution.

53. Any Member, Associate Member, Associate, or Student retiring from the Institution shall continue to be liable for Annual Subscriptions until he shall have given formal notice of his retirement to the Secretary. Contributions payable by Members, Associate Members, Associates, or Students shall

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be debts due to the Institution, and may be recovered by the Treasurer.

Remission of Subscription in certain cases.

54. In the case of any Member or Associate who has been long distinguished in his professional career, but who, from ill health, advanced age, or other sufficient cause, does not continue to carry on a lucrative practice, the Council, if they think fit, may remit the Annual Subscription of such Member or Associate, and they may remit any arrears due by him. Any such case must be considered and reported upon to the Council by a Committee appointed by the Council for the purpose.

Council may refuse to receive subscriptions in certain cases.

55. The Council may refuse to continue to receive the subscription of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall, in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution, and may remove his name from the Register, and he shall thereupon cease to be a Member, Associate Member, Associate, or Student (as the case may be) of the Institution.

Section IX.—General Powers and Provisions.

Powers of Institution in General Meeting.

56. Any Extraordinary or Special Meeting of the Institution, duly called, shall have power by a majority in number of the persons present thereat entitled to vote, from time to time, to review the decisions or determinations of the Council; to remove Members of Council; to expel Members, Associate Members, Associates, Students, or Honorary Members from the Institution, and to expunge their names from the Roll; and to delegate to the Council all such further powers as may be considered necessary for efficiently performing the

To delegate powers to Council.

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business of the Institution. At any Extraordinary or Special Meeting 50 Members shall be a quorum.

57. The Institution shall have a common seal, which will be under the charge of such of the Office-Bearers as the Council may appoint, and all instruments bearing the seal shall be countersigned as the Council shall direct. Common Seal.

Section X.—NOTICES.

58. Notices requiring to be served by the Institution upon its Members, Associate Members, Associates, Students, or Honorary Life Members may be served either personally, or by leaving the same, or by sending them through the post; and notices so posted shall be deemed to have been duly served. No Members, Associate Members, Associates, Students, or Honorary Life Members who have not a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to any such. Notices.

59. Notices for any General or Extraordinary or Special Meeting of the Institution must be given by the Secretary to all Members, Associate Members, Associates, or Honorary Life Members at least four days before such meeting. Notices of any adjourned meeting shall be given at least two days before the adjourned meeting is held. Such notices shall specify the nature of the business to be transacted, and no other business shall be transacted at that meeting. Inducie of Notices.

60. Notices for any meeting of Council must be given by the Secretary at least four days before such meeting. Notices for the meeting of Committees shall be given as the Council shall direct. Notices.

61. In computing the *inducie* of any notice, the day on which the same is delivered shall be reckoned as an entire day. Computation of Inducie.

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APPENDIX.

Form *A*.

Form of Recommendation and Undertaking.

A. B.....of.....being upwards of.....years of age, and being desirous of belonging to the Institution of Engineers and Shipbuilders in Scotland, I recommend him, from personal knowledge, as in every respect worthy of that distinction because (here specify distinctly the qualifications of the Candidate according to the spirit of Articles 5, 6, 7, and 8).

On the above grounds I beg leave to propose him to the Council as a proper person to belong to the Institution.

.....*Member.*

Dated this.....*day of*.....19

We, the undersigned, from personal knowledge, concur in the above recommendation.

.....*Member.*

.....*Member.*

I, the said A. B., do hereby promise that in the event of my election I will abide by the Rules and Regulations of the Institution, and that I will promote the objects of the Institution as far as may be in my power.

.....

The Council having considered the above recommendation present A. B. to be balloted for as.....of the Institution of Engineers and Shipbuilders in Scotland.

Passed by the Council.....19

Balloted for.....19

.....*President* (*or Chairman*).

Form *B*.

Form for Transfer from one Class to another.

A. B.....of.....having been a.....of the Institution of Engineers and Shipbuilders in Scotland for.....years, and being desirous of becoming a.....of the Institution, we, from personal knowledge, recommend him as in every respect worthy of being elected a.....of the Institution.

.....*Member.*

.....*Member.*

.....*Member.*

I, the said A. B., do hereby promise that in the event of my election I will abide by the Rules and Regulations of the Institution, and that I will promote the objects of the Institution as far as may be in my power.

.....

The Council having considered the above recommendation and undertaking approve of the same.

.....*President* (*or Chairman*).

Dated this.....*day of*.....19

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BYE-LAWS.

MEDALS AND PREMIUMS.

Marine and Railway Engineering Medals.

1. Each of the two Medals founded by subscription, for the best paper in the Marine and Railway Engineering Departments respectively, shall be awarded by the vote of a General Meeting, not oftener than once in each Session.

Institution Medal.

2. The Council shall have power to offer annually a Medal for the best paper on any subject not comprehended by the Marine and Railway Engineering Medals. Such additional Medal to be called the Institution Medal, and to be paid for out of the funds of the Institution, until a Special Fund be obtained. This Medal also shall be awarded by the vote of a General Meeting.

When Medals may not be awarded.

3. If it shall be the opinion of the Council that a paper of sufficient merit has not been read in a particular department during any Session, the Medal shall not be given in that department; and, in the case of the Marine and Railway Engineering Medals, the interest arising from the particular Fund shall be added to the principal.

Medals and Books may be awarded.

4. If the person to whom a Medal may be awarded shall express a wish to receive a Bronze Medal, accompanied with the extra value in books, in lieu of the ordinary Gold Medal, the award shall be made in that form. The Council may recommend premiums of books in lieu of, or in addition to, the Gold Medals. The value of such premiums of books to be determined by the Council.

MANAGEMENT OF THE LIBRARY.

Appointment of Library Committee.

5. The Council, at their first meeting each Session, shall appoint eight of their number to form a Library Committee, one of the eight to be Honorary

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Librarian and Convener of the Committee. Three Members of the Committee shall form a quorum.

Secretary shall have charge of Library.

6. The Secretary of the Institution shall have charge of the Library, and shall also act as Secretary of the Library Committee.

Powers of Library Committee.

7. The Library Committee, subject to the sanction of the Council, shall expend in books and Library expenses the sums placed at their disposal, and, subject to the approval of the Council, may make Bye-Laws for the management of the Library, and appoint Assistants. The sum of £30 or thereby shall be expended annually out of the funds of the Institution, in the purchase of books for the Library, in addition to the ordinary expenditure in binding, etc.

Duties of Library Committee and Annual Report.

8. The Library Committee shall annually make an examination of the property in connection with the Library, and report to the Council, detailing the state of the Library affairs.

LIBRARY BYE-LAWS AS TO USE OF BOOKS.

When Library is to be open.

9. Except during Holidays and Saturdays, the Library shall be open each lawful day from 1st May till 30th September inclusive, from 9.30 a.m. till 5 p.m. On Saturdays the Library shall be open from 9.30 a.m. till 1 p.m. On the 1st October and thereafter throughout the Winter Session the Library shall be open each lawful day from 9.30 a.m. till 8 p.m., except on meeting nights of the Institution and Royal Philosophical Society, when it shall be closed at 10 p.m. The Library shall be closed for the Summer Holidays from the 11th July till 31st July inclusive.

Who may borrow books.

10. Books shall not be lent to any persons except Members, Associate Members, Associates, Students, or Honorary Members of the Institution; but a person entitled to borrow books may send a messenger with a signed order.

11. The books marked with an asterisk in the

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Catalogue shall be kept for consultation in the Library only, and shall not be lent. Books for consultation only.

12. The Librarian and Assistant Librarian shall take their instructions from the Secretary of the Institution. They shall keep an Accession Book, in which shall be entered the particulars of all books purchased for or donated to the Library. Librarian to keep Accession Book.

13. The Librarian, or Assistant Librarian, shall keep a Register in which he shall enter the titles of the book or books lent, the date of lending, the name of the borrower, and the date of the return of the book or books to the Library. Register kept of books lent.

14. The borrower of the book or books, or, in his absence, the bearer of his order, shall sign his name to the entry of such borrowing in the Librarian's Register. Borrower to sign for books.

15. The Librarian, or Assistant Librarian, shall sign his initials to the date of the return of the book or books. Librarian to certify return of books.

16. The borrower shall be responsible for the safe return of the book, and if it be damaged or lost he shall make good such damage or loss. Should books be returned in a damaged condition, the Librarian, or Assistant Librarian, shall immediately make an entry of the fact in the Register, and report the same to the Library Committee without delay; and he shall give notice in writing of such entry, and report to the person from whom he last received the book, within three clear days of the receipt of the book, exclusive of the day of receiving the book and the day of giving such notice. Books damaged to be entered in Register. Intimation to Library Committee, and notice to last borrower.

17. No person shall be entitled to borrow, or have in his possession at one time, more than two complete works belonging to the Library, or two volumes of any periodical. Number of books which may be borrowed at one time.

18. No person being six months in arrears with his subscription to the Institution shall be at liberty to use the Library or Reading Room. Persons in arrears of Subscription not to have use of Library.

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Time books may be obtained.

19. No borrower shall have the right to retain a book longer than thirteen clear days, exclusive of the days of borrowing and returning; and written notice shall be sent to the borrower one day after the time has expired. In no case shall any book be kept longer than twenty clear days.

Lots to be drawn when two may apply for the same book.

20. In the event of two or more persons applying for the same book at the same time, the applicants shall draw lots for priority.

Introduction of friends to Reading Room.

21. Each Member shall be entitled to introduce a friend to the Reading Room, whose name shall be written in the Visitors' Book, together with that of the Member introducing him

Annual scrutiny of books.

22. All books belonging to the Library shall be called in for inspection, and the lending out of books shall be suspended in each year for one week, being the last seven clear days of March; and all Members shall be required by an intimation to be inserted in the notice calling the preceding meeting of the Institution, to return all books in their hands to the Library on or before the day next preceding the period before mentioned.

NOTE.—The Library and Reading Room are open to Members, Associate Members, Associates, and Students; and the Library of the Philosophical Society is open for consultation.

WILLIAM BROWN, *Convener.*
WILLIAM M. ALSTON.
PROF. A. BARR, D.Sc.
W. A. CHAMEN.
E. HALL-BROWN.
WILLIAM MELVILLE.
JOHN STEVEN.
JOHN WARD.
EDWARD H. PARKER, *Secretary.*

21*st April*, 1903

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INSTITUTION
OF
ENGINEERS AND SHIPBUILDERS
IN SCOTLAND
(INCORPORATED).

PRESIDENTIAL ADDRESS

By A. J. CAMPBELL,
President of the Institution.

6th October, 1925.

GENTLEMEN,

First of all, let me say how much I appreciate the honour you have bestowed on me in electing me President of the Institution in succession to so many eminent engineers and shipbuilders. I accept the charge with great diffidence, being fully conscious of my shortcomings, but I assure you that I shall do my utmost to develop the interests and maintain the traditions of our Institution.

Having in mind the condition of the shipbuilding and engineering industry, I have decided to give a brief running review of the present position, as compared with that immediately preceding the great war.

To-day there are about 96 shipyards in Britain, of which a number have marine engine works associated with them. In 30 of these yards there is not a single keel laid; in 15 any work in hand is rapidly nearing completion, while the remaining works are barely occupied beyond one-fourth of their capacity.

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The present serious condition of the shipbuilding industry will be understood when it is known that the number of building berths in this country to-day is 20 per cent. more than in the year preceding the war, and only 28 per cent. of the berths are occupied, while the percentage of unemployed workmen is between 30 and 40, which is really appalling.

The gross tonnage of merchant vessels building at the end of June last in Great Britain and Ireland was about 1,100,000, as compared with 1,900,000 building during the 12 months preceding the war. In 1913 about 3,333,000 tons were launched, of which almost 2,000,000 were built in Britain and her colonies, while the world's work in hand in June last was slightly over 2,333,000 tons. Of this, 1,100,000 tons is being built in Great Britain and Ireland. That is to say, in 1913 we built about 60 per cent. of the world's output, while at the present time we are building only 46 per cent. Our leading competitors, in order of tonnage building at the end of June, were Germany, Italy, France, Holland, and the United States.

Various reasons are urged as accounting for the decline in home shipbuilding and the increase abroad, such as rates of exchange, working hours, subsidies, and working conditions generally. No doubt the general position abroad is somewhat exceptional, and as these conditions tend towards normal the pendulum will swing back in our favour, but we are bound to accept the conclusion that we cannot possibly regain the position in which we were able to account for 60 per cent. of the world's output.

An examination of the ownership of the world's tonnage to-day, as compared with the ownership in 1914, will help us to realise this. The world's tonnage in 1914 was 42,500,000 gross; to-day it is 58,750,000. The percentage owned in Britain in 1914 was 44½; to-day it is under 33. The United States, which owned just over 4 per cent. of the world's tonnage in 1914, to-day owns about 20 per cent. The other leading countries, in order of tonnage owned, are Japan, France, Germany, Italy,

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Holland, and Norway. Germany now owns 2,100,000 tons less than in 1914. During the year ending in June last, the tonnage owned increased; in Great Britain and Ireland by 333,000 tons, in Italy by about 200,000 tons, and in Norway by about 166,000 tons. A considerable reduction is shown in the United States tonnage owned, which is now over 500,000 tons less than a year ago. When the abnormal conditions arising from the war disappear, these figures will no doubt tend towards the proportion existing in 1914, but a complete restoration cannot be expected.

Before passing from the question of the world's supply of tonnage, it is interesting to look for a moment at the rate of depletion of the world's merchant tonnage. Recently Lloyd's published a statement of the number of vessels broken up, which is tabulated as under. It will be noted that the figures vary to an enormous extent from year to year.

Years.	Minimum Tons.	Maximum Tons.
1905-1909	120,003	251,900
1910-1914	87,737	245,891
1915-1920	In these years practically no tonnage was broken up, the yearly average amounting only to 10,000 tons.	
1921	77,500 tons.	
1922	315,000 ,,	
1923	963,000 ,,	
1924	1,174,000 ,,	

The most recent returns show a decided falling off in the amount of tonnage being broken up. I suggest that the shipbuilder and shipowner should jointly consider, in their common interests, what is the best method of disposing of old and inefficient tonnage. As time goes on it becomes more apparent that we should take a more corporate view of this and other cognate subjects. We act too independently and unheed-

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ingly of one another, to our mutual disadvantage. Could old and obsolescent ships not be offered in part payment for new ships, instead of being sold to foreign competitors for sums, in many cases, not much more than their scrap value? Our position among the nations as owners and builders would thus be conserved.

There is no doubt that, to a large extent, the tonnage owned by foreign countries has been swollen by the acquisition of ships from this country which were already more or less inefficient. They can, however, successfully compete with British ships, as their national requirements are not so stringent as ours, and much lower wages are paid than in Britain. As these obsolescent ships disappear, the balance can only be maintained by the purchase of new tonnage. Our hope is that we shall be able to establish our old position of the most economical shipbuilding and engineering country, as the conditions presently affecting the production of foreign tonnage disappear.

The following statement of the employment of coal and oil fuel at the present time, as compared with 1914, is also published by Lloyd's, and is interesting:—

	1914. Percentage of total gross tonnage.	1925. Percentage of total gross tonnage.
Sailing vessels and sea-going barges	8·06	3·5
Oil, etc., in internal-combustion engines	·45	4·2
Oil fuel for boilers	2·65	27·54
Coal	88·84	64·76

It will thus be seen that 64¾ per cent. of the tonnage of the Merchant Marine now depends entirely upon coal, while in 1914 the percentage was nearly 89, and the use of fuel oil has increased from 3·1 to 31·74 per cent. These figures give an

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indication of what may be looked for in the next decade in the use of oil. The tonnage of motor vessels now building in the world amounts to 1,088,000, while the tonnage of steam vessels under construction is 1,090,000, that is, the tonnage of motor-driven vessels practically equals that of steam-driven vessels. At the end of June last, in Great Britain and Ireland, the tonnage of motor vessels amounted to 58 per cent. of the steam tonnage under construction. In Denmark, Germany, Holland, Italy, and Sweden the motor tonnage under construction greatly exceeds the steam tonnage, the combined totals for these five countries being 250,000 tons of steamers, and 625,000 tons of motorships. The world's figures include 115 motorships between 5,000 and 10,000 tons, five between 10,000 and 15,000 tons, and seven between 15,000 and 25,000 tons.

Although we hold an inferior position compared with the rest of the world, and particularly with our Continental neighbours, in the relative proportion of motor vessels to steam vessels building, it is comforting to know that of the largest vessels with internal-combustion engines we are producing the greater quantity, and as members of this Institution we can congratulate ourselves that the largest motorship, the "Aorangi," is a Clyde product, and maintains her station on the Pacific between British Columbia and New Zealand with the regularity of her sister steam-driven ships.

The above table shows that in 1914 only ·45 per cent. of the world's merchant tonnage was fitted with internal-combustion engines. That year is, therefore, the real starting point, but it cannot be forgotten that from 1914 to practically 1919 this country had to concentrate all its shipbuilding and engineering energies on the production of vessels and munitions of war for national defence, and during the latter part of the period to replacing, as rapidly as possible, the merchant tonnage of all classes lost during the war. Consequently, there was not an opportunity to develop the internal-combustion engine,

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but our Scandinavian neighbours, not being directly engaged in the war, took full advantage of the circumstances to perfect their plant and methods of production, and to manufacture to such an extent as to be in a position to compete successfully with us in economy of production.

The progress made in all the arts of mechanical and marine engineering during the last generation has been such that the influence of the nature and performance of propelling machinery on the success of all types of vessels has become increasingly great, until to-day it may be said almost to be the dominant factor.

Gradually, a broader-minded outlook induces the shipowner to give a trial to novel systems of propulsion, in the hope of improving the economy of performance of his ships. In the last decade, to some considerable extent, the erstwhile standardised and highly-developed triple-expansion reciprocating steam-engine with coal fuel has had to give place in turn to the direct-coupled steam turbine with oil fuel, to mechanical gearing associated with steam turbines, and lastly, to the internal-combustion prime mover. Nor at the present time is there any distinct sign of any real narrowing down of the issue in respect of the technical fundamentals.

However much it may be regretted that such severe technical competition, as is necessarily involved, should coincide with a period of general world trade depression and financial stringency, it must be realised that the race for maritime supremacy must be carried on at a pace far greater than was dreamt of by our predecessors, due to the growing technique of our engineering competitors.

In looking back over the proceedings of this Institution, I could not but be impressed by the summary of the position of marine propulsion, and the forecast of the future development given by the late Mr. E. Hall-Brown on the occasion of his Presidential Address, delivered on the 24th October, 1911—14 years ago.

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He saw that the great invention of the steam turbine had revolutionised thought in the minds of marine engineers, and had made the shipowner receptive of new ideas. The younger generation would be well advised to follow carefully much of the advice given in that able address. When predicting success for mechanical gearing as a means of attaining reasonable approximations to maximum efficiency of the prime mover and of the propeller, he was emphatic in stating that it is always the speed of revolution of the propeller which must be the governing factor in the design of marine propelling machinery.

The predictions there made of the gradual increase in numbers of ships equipped with Diesel oil engines have been more than amply fulfilled, and it is interesting to review the progress made. In 1897, the first Diesel oil engine with a very small horse-power was publicly tried in Germany by Prof. Schröter. This engine is now in the German Museum in Munich. Fourteen years later, when Mr. Hall-Brown gave his address, two hundred horse-power per cylinder was an established power at sea, and engines of 1,000 b.h.p. per cylinder were being constructed experimentally. At the present time, exactly 14 years later, massive engines of 1,000 b.h.p. per cylinder are being installed in Atlantic liners. In 1911 the battle of the four-stroke *versus* the two-stroke cycle principle of operation of the Diesel engine was raging, and there is no great abatement to-day of discussion on this important technical issue. The greatest proportion of engines at sea and building, work on the better established four-stroke cycle principle. The first engines of this great power are now being fitted on board large Atlantic liners, and it is interesting to reflect that these engines, which have been proved by exhaustive trials on the test-bed, are of the double-acting four-stroke cycle principle.

In 1911 the geared reciprocating engine was suggested by your President, and to-day the large single-screw motorship

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"Duisburg" has completed a most successful maiden voyage, 4,000 b.h.p. being developed by two single-acting four-stroke cycle Diesel engines geared to a single propeller running at 75 revolutions per minute, so following the principles as then laid down.

The economic side of the Diesel oil engine has never been clearly stated. Throughout the whole history of the motorship, it has apparently been proved on paper that, since the amount of fuel required by a motorship is from one-third to one-fifth of that required by a coal-fired ship, the savings can be *nil*, as the prices of coal and oil, at any rate in home ports, are in the same proportion. These, after all, are facts which only the shipowner can give, and it is to be again regretted that shipowners generally do not act corporately with us and take a greater part in the affairs of our Institution, giving to the constructors the benefit of their actual commercial experience. The fact remains that on a great number of our important trading routes the motorship is to-day showing enormous economies over steamers, and whilst shipowners will not put their cards on the table yet, the mere fact of repeated and consistent construction of this type of vessel is satisfying evidence. The explanation no doubt is that with the motorship, contracts for oil fuel are obtained by shipowners at a very much lower rate per ton than is published. The savings with motor engines in reduced stand-by losses, much more economical working of cargo, reduced cost of personnel, and increased deadweight, have a very marked bearing on the balance sheet of the ship.

Whether the large passenger liner of the future will be propelled by internal-combustion reciprocating engines, or by improved and more efficient turbine steam-generating plant, is still an open question. The advantages of minimum upkeep and maintenance with rotary engines are considerable, although those who are now adopting Diesel engines for transatlantic vessels are shipowners with the maximum experience of the

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Diesel marine prime mover. Extraordinarily keen research into the laws governing the heat transmission from the combustion to the cooling medium, combined with the increased adherence in the iron foundry to the results of metallurgical research, have reduced the heat difficulties, which were formerly regarded as mounting up most rapidly with small increases in the sizes of the main cylinders.

On the other hand, quadruple-expansion reciprocating engines with high-pressure steam, and the high superheat which can be safely used with valve gear of the poppet type, associated with intensive preheating and feed-water heating, is a proposition well worthy of study, in which there may be great possibilities, such as shortening the engine-room length, and reducing the fuel consumption by an amount greater than that achieved by the turbine when it was first introduced.

So keen to-day is the competitive race in the world that only the highest technique can hope to be fully successful, and in all these multifarious new developments, each striving to outdo the other, future generations must be so equipped as at least to maintain their place in the race. To this end, Institutions such as ours have played, and are destined to play, no small part. The magnitude and importance of the activities, however, are largely in the hands of the members themselves, and particularly of the younger members.

If from any of the foregoing remarks I may be understood as entertaining a pessimistic view of the present industrial condition and its immediate future, I beg at once to state that I do not. I feel confident that the engineers and shipbuilders of our country are as able to-day to face a trade depression as they ever have been in the history of our industry. Our young men are just as keen as their predecessors to apply themselves to the situation, and I am sure they get every encouragement in their work. It must further be stated that we can count on the great body of expert workmen with whom we are daily associated maintaining that pride of workmanship

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which has always characterised them, as well as that strong desire to uphold the traditions established by their fathers.

Prof. P. A. HILLHOUSE, D.Sc., (Vice-President): We have listened to a very instructive and interesting address by our new President. I heard somebody say recently that when business was flat on its back it must be looking up, and I am sure you will be glad to know that, although Mr. Campbell has drawn attention to the depressed condition in which our industry presently stands, he is by no means pessimistic concerning it. It is my duty to ask you, gentlemen, to join me in offering Mr. Campbell a very enthusiastic and hearty vote of thanks for his interesting and illuminating address.

The vote of thanks was carried with acclamation.

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THE RUTHS STEAM ACCUMULATOR.

By ALFRED J. T. TAYLOR,
Member of the Institution.

6th October, 1925.

LAST year, at the World Power Conference, Dr. Johannes Ruths, an eminent Swedish engineer, presented a paper on his Steam Accumulator. The importance of this accumulator was referred to in six other World Power Conference papers by European engineers. The system designed by Dr. Ruths had, up to that time, been the subject of over 200 technical articles in foreign languages, and been applied beneficially in 160 industrial plants, comprising 17 distinct lines of manufacture. The accumulator had been definitely out of the experimental stage for over four years, yet in July, 1924, there was only one Ruths accumulator in the British Empire and only two others in the rest of the English speaking world. Not a single technical paper in the English language had dealt comprehensively with Dr. Ruths' inventions.

The present paper is an attempt to bring together sufficient information to form an adequate introduction to the study, by English speaking engineers, of what I believe to be the most far-reaching invention in the field of industrial steam engineering during the past fifteen years.

In support of this statement, I would direct attention to the fact that no single invention has more profoundly affected recent European steam practice than the Ruths accumulator. Its influence may be seen in the development of high-efficiency non-condensing turbines, in the work on high-pressure boilers,

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and it lies at the root of the whole scheme of modern thought in exhaust-steam engineering.

Thermal storage was studied and applied in this country 30 years ago. Druitt-Halpin used his system of feed-water storage in many plants, and did work along these lines far in advance of his time. Rateau's accumulator was adopted and extensively written about, but both these systems were limited in their usefulness, and together have to some extent retarded an earlier general adoption in this country of the idea of steam storage. English speaking engineers, familiar with the limitations of prior developments in the art of steam storage, have felt until recently that the work being done in Scandinavia and on the Continent along these lines was but a variant of work previously done here, and, therefore, suffered from similar limitations. It is partly as a result of this attitude that the entire English speaking world has been about three years late in grasping the significance of the Ruths steam accumulator system.

In the opening paragraph to my last paper* read before this Institution, I pointed out that inventions naturally develop faster in the country where they first receive commercial protection. It is not my intention to criticise, in the present instance, my fellow British engineers for tardiness in adopting the accumulator, but there is certainly no longer a reasonable excuse for lack of knowledge of this invention, nor neglect of its possibilities, to bring our own industrial plants to a higher state of commercial efficiency.

Scope of the Paper.

This paper aims to accomplish four things. Firstly, to draw attention to the fact that there is a complete practical system of steam storage in the Ruths accumulator and to describe its operation. Secondly, to demonstrate, by means of four actual cases in four distinct applications, methods by which the

* "Pulverised Fuel in Some Commercial Aspects," October 14, 1924.

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accumulator can be efficiently applied. Thirdly, to give a complete list of all installations of the Ruths accumulator system, so that engineers may be able to correspond with the owners or visit directly those plants that interest them most. Fourthly, to include as complete as possible a bibliography of papers previously written on the subject, so that it may be readily referred to by those who wish to continue the study of this important matter.

The essential ground to be covered by the paper does not allow space in which to discuss previous attempts at steam storage, or to contrast the Ruths accumulator system with other systems of thermal storage.

Development of Ruths' Idea.

As managing director of some of the foremost plants in both the steel and paper industries in Europe, Dr. Johannes Ruths conducted a number of studies and tests in industrial plants with a view to effecting the highest efficiency and production of the entire plant, and out of these investigations grew the Ruths steam accumulator system, which, as will be seen from the accompanying list of installations, has already been applied in more than 200 industrial plants.

Relatively few investigations have been made of the effect that variations in the consumption of steam or power exercise on the working methods and overall efficiency of our industrial plants. These variations, which are often much greater than is generally known, have been accepted as unavoidable; and attempts have been made to counteract their effects by providing greater flexibility in the firing apparatus.

All firing equipment has a certain time lag in responding to changes in load conditions, and during this period the operating efficiency falls off. There is one definite point in the output of steam for each boiler when the overall efficiency of the unit is at the maximum, the efficiency being less at any other point. Widely fluctuating loads in a boiler plant do

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more to affect adversely the economical generation of steam than any other single influence. The accumulator makes possible the absorption of all fluctuations between demands for power and demands for steam, regardless of where and when they occur in the factory.

There are few factories in which all parts correspond to one another at the output. There is usually one part of the plant which is not quite as productive as the rest, and in nearly every instance it is the boiler house which is at fault. It is a point of primary importance in very many factories carrying on a sensitive chemical or drying process that, the steam employed must have a definite temperature. Unless this temperature is kept steady the process suffers, and the quality of the article produced is impaired. With a fluctuating demand for steam and without an accumulator, it is often extremely difficult to keep the boiler pressure and the required steam temperature constant. It frequently happens that the importance of definite temperature outweighs all other considerations.

Principle of the Ruths Accumulator.

The Ruths accumulator is based on the principle of storing in a large quantity of water under pressure and at saturation temperature the heat energy of steam, and releasing this energy in the form of steam under decreasing pressure. This principle is not new. It was used by Prof. Rateau, but only for the purpose of utilising over very short periods the intermittent exhaust from steam-driven machinery. The Rateau accumulator had no influence on steam fluctuations in the boilers, whereas the Ruths accumulator provides for storage capacity which will accommodate wide fluctuations in steam demand over periods of hours if necessary, and is in fact, by analogy, the fly-wheel of the boiler plant. Fig. 1 is a set of curves showing the steam storage capacity of water.

For example, if a pressure of 400 lbs. in a boiler is lowered

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to, say, 350 lbs., Fig. 1 shows that ·8 lb. of steam will be obtained from each cubic foot of water. The Ruths steam accumulator can be arranged to work under much lower pressures, say between 60 and 10 lbs. For this pressure range the curves show a storage capacity of 4·2 lbs. of steam per

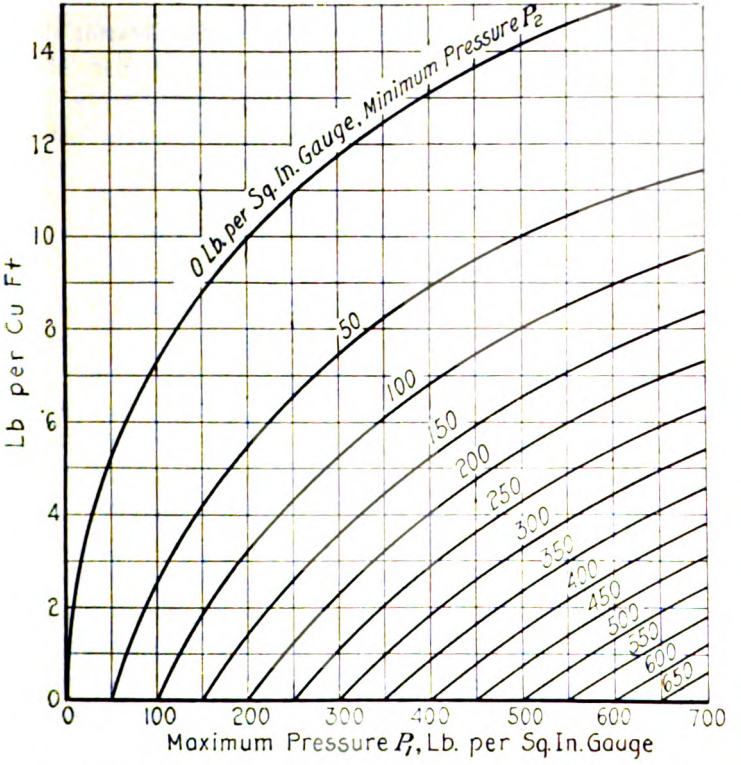

Fig. 1.—Diagram showing the amount of steam evaporated from 1 cubic foot of water when pressure is decreased from P_1 to P_2.

cubic foot of water. Thus, for the same pressure drop of 50 lbs. the storage capacity of the accumulator may be five times larger than in the modern boiler for the same quantity of water. In addition, the boiler in this example has to be built to withstand 400 lbs. pressure and the accumulator only 60

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lbs. Steam storage capacity in an accumulator can, therefore, be obtained much more cheaply than in a boiler. Usually large pressure-fluctuations as assumed above are not allowed to take place in the boiler, and so the difference between the comparative steam storage capacity of boilers and accumulators is increased still further. These figures clearly show that steam boilers should be built only for the purpose of generating steam at a constant rate, and that all superfluous water space should be arranged for in a separate receptacle, built for a lower pressure, in which much wider pressure-fluctuations may be allowed than in the boiler.

Influence on High-Pressure Boilers.

We are undoubtedly moving towards higher boiler-pressures, and as these increase, so for economical reasons must the water space in the boiler diminish, and consequently the accumulating capacity of the boiler decrease. The water space in a boiler is, in effect, a steam accumulator, and the accumulating effect of a large water content in boilers of the Lancashire type is an important reason why this type of boiler has persisted in those industries like cotton spinning, where the load fluctuates rapidly over a wide range. The commercially ideal high-pressure boiler would consist of tubes only, and this being presently impossible, designers, for reasons of economy in cost, seek for the minimum size of those pressure parts that are required to connect the tubes together, and with the resultant decreased water capacity in the boilers the heat storing or accumulating capacity becomes almost negligible. It is, therefore, necessary to supply such capacity in separate accumulators. The deficiency cannot be met by flexibility in the firing apparatus.

In this connection, it is significant that Dr. Frederick Münzinger in his paper before the World Power Conference on "High-Pressure Boilers" writes: "One can see, according to our present knowledge, that in many cases the economical use

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of high-pressure steam in stations with high peaks could probably only be made possible by the installation of such accumulators."

Construction of the Ruths Accumulator.

The accumulator is built in the form of a cylindrical steel tank with hemispherical ends. Its volume is so large in comparison with its exterior surface that an insulation of 3 to 4 inches in thickness is sufficient to reduce the heat loss to a negligible amount. It is usually installed in the open air without building protection. The plant consists of two parts, the accumulator proper and the automatic valves which control the co-operation of the boilers and the accumulator, and which also govern the steam distribution throughout the whole steam system of the works.

Fig. 2 shows a complete accumulator installation. The tank A is constructed of riveted steel plates, and filled about 90 per cent. full of water. Over this is a covering B of non-conducting material, with insulation blocks C covering the riveted seams of the shell, easily removable for the inspection of the seams. This lagging is protected by a light sheet-iron cover D.

The non-return valve E admits charging steam to the internal steam-distribution pipe F and the charging nozzles G, which are equipped with circulation pipes H to ensure a uniform and noiseless heating of the water. Through a non-return valve I the discharge of steam takes place. A de Laval nozzle K limits, in case of emergency such as a rupture in the steam piping, the maximum discharge of steam from the accumulator to an amount which will not allow priming. A water column L and feed valves M are provided for reading and adjusting the water level in the accumulator.

Condensation of steam in the accumulator, due to radiation losses, tends to increase the average water level, but the fact that the accumulator is charged with steam of higher pressure

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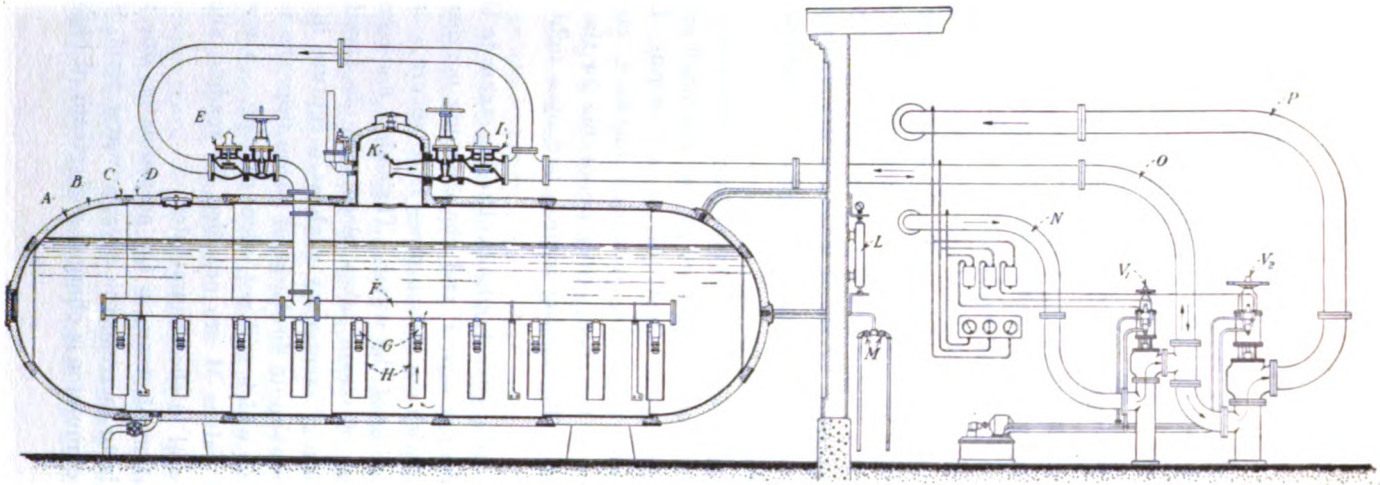

Fig. 2.—Ruths Accumulator Installation, showing section through Accumulator and Steam Switchboard to the right.

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and higher heat content and discharges steam at lower pressure, *i.e.*, that it is consequently discharging more steam than it is taking in, counterbalances the condensation so well that a readjustment of the water level is seldom required.

The accumulator shell is supported by four cast-steel brackets, so placed as to distribute the bearing reactions properly and provide for the free expansion of the accumulator shell under the wide variations of pressure and temperature of the water it contains. One supporting bracket is rigidly fixed, while two others rest on rollers, one permitting longitudinal and the other lateral displacement. The fourth is a pendulum support allowing displacement in either direction.

Capacity of the Accumulator.

The capacity of an accumulator for a given plant is determined by the magnitude of the fluctuations of the steam consumption only, and not by the capacity of the boiler plant. Thus a steam-flow chart showing the total steam consumption of the plant, or, if the steam consumption is fluctuating in one department only, a chart from this department will be sufficient for calculating the capacity of the accumulator. The storage capacity must be equal to the largest surface area on the chart above or below the line of the average steam demand.

The volume of the accumulator is a function of the required accumulating capacity and the permissible pressure drop. Fig. 1 shows the relationship between maximum pressure, minimum pressure, and storage capacity of one cubic foot of water at different drops in pressure. By using this diagram the required volume of the accumulator can be easily calculated. Suppose the accumulator is connected between two pipe lines carrying pressures of 150 lbs. and 50 lbs. per square inch respectively. According to the diagram, one cubic foot of water can then store 4·2 lbs. of steam. If a storage capacity of 25,000 lbs. of steam is desired, and 90 per cent.

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of the accumulator volume is occupied by water, the volume of the accumulator will be

$$\frac{25{,}000}{4{\cdot}2 \times 0{\cdot}9} = 6{,}613 \text{ cubic feet.}$$

Steam accumulators have been built in sizes of from 200 to 13,000 cubic feet volume, and in one mill an accumulator installation of a total volume of 37,000 cubic feet with a capacity of 150,000 lbs. of steam has been erected. This accumulator was subdivided into three separate tanks. The total volume of all Ruths accumulators now in operation or under erection is 960,000 cubic feet., with a total capacity of about 3,700,000 lbs. of steam and a water weight of about 56,000,000 lbs.

Automatic Control.

Of the highest importance in the proper functioning of the accumulator system is the regulating equipment, which, by analogy, may be called the steam switchboard.

The arrangement of the steam accumulator in the power plant must be such that it is connected between a high-pressure and a low-pressure steam line. At times, when there is an excess of steam supply over requirements, steam flows from the high-pressure line to the accumulator, causing in it a rise of pressure. At other times, when there is a peak load in the plant, steam flows from the accumulator to the low-pressure line, causing in the accumulator a drop of pressure. The pressure in the steam header is always kept constant, and the accumulator pressure only is allowed to vary.

Fig. 3 shows an arrangement often used in industrial plants. Steam is generated in the boiler house at, for instance, 150 lbs. per square inch pressure, and reduced by means of a reducing valve RV to 25 lbs. Due to a fluctuating steam demand, the boiler pressure cannot be kept constant. Ruths' idea in theory was to insert an overflow valve OV, Fig. 4.

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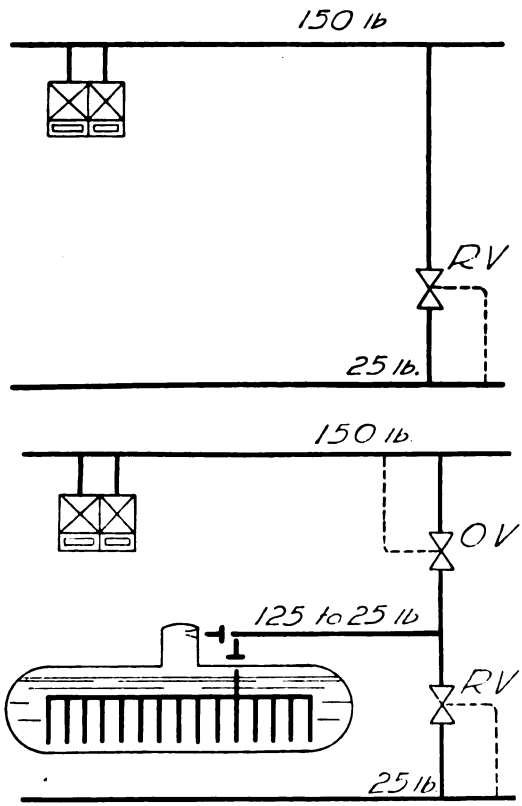
which only passes enough steam to maintain a constant pressure in the boiler. In most cases, however, the steam supply through OV and the steam demand through RV are not always equal, and there is a difference in time between them. There-



Figs. 3 and 4.—Development of Automatic Valve Control.

fore a steam storing device, *i.e.*, a steam accumulator, has to be inserted between OV and RV capable of storing enough steam to maintain the balance. If the pressure in the accumulator drops to 25 lbs., and there is still demand for steam in excess of the supply from the boilers, the low pres-

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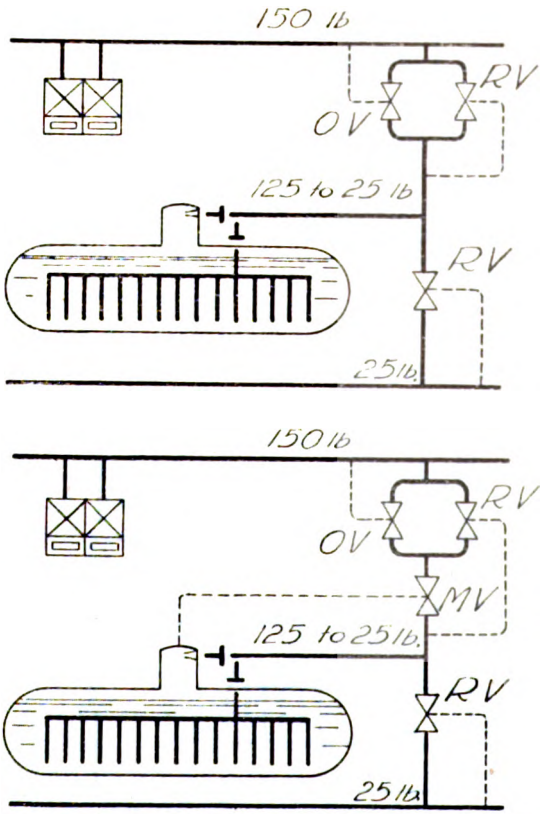
sure will drop below 25 lbs. To prevent this, a reducing valve RV is connected in parallel with OV by-passing sufficient steam to maintain the low pressure regardless of the condition of OV, Fig. 5. Often the accumulator is built for a lower



Figs. 5 and 6.—Development of Automatic Valve Control.

pressure than that of the boilers, for instance, for 125 lbs. In this case a valve is required which will protect the accumulator from being overcharged, *i.e.*, a valve MV, Fig. 6, which throttles the supply of steam if the accumulator

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pressure reaches 125 lbs. regardless of the condition of the valves OV and RV. By using these four valves an absolute balance and constant pressure are maintained, except under extreme conditions beyond the range for which the particular plant has been designed.

In practice the arrangement as shown in Fig. 6 has been improved by combining in a single valve all the functions of valves OV, RV, and MV. In Fig. 2 it will be seen that the steam switchboard, consisting of the two automatic regulating valves V_1 and V_2 which control the charging and discharging of the accumulator and maintain constant pressures in the factory steam mains, does everything that the four valves shown in Fig. 6 could do. In the present case it may be assumed that valve V_1 is connected to the boiler main N, and is controlled by the boiler pressure in such a way as to maintain it constant. That is, the valve acts as an overflow valve for the boiler, being set for a pressure slightly lower than the safety valves. The popping of the safety valves on the boilers will always be prevented, and when steam is generated in excess of the pressure for which the valve is adjusted it will automatically pass through this valve into the accumulator line O. A reducing valve V_2 maintains a constant pressure in line P leading to the steam consumers. According to whether at a given moment more or less steam is passed through valve V_1 than through valve V_2, the accumulator will be charged or discharged.

In case the accumulator should happen to be charged up to its maximum pressure, V_1 acts as a maximum-pressure valve, and will shut off further steam supply to the accumulator. On the other hand, if the accumulator should happen to be completely discharged, V_1 acts as a reducing valve securing a sufficient supply of steam to the secondary steam line P, despite the fact that the accumulator is discharged.

In order to obtain correct co-operation of the different

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functions of these control valves, an extreme sensitiveness of the pressure regulation is required. The principle of the relay developed for these valves is shown in Fig. 7. The motion of the steel diaphragm A, which is exposed to the steam pressure admitted through pipe B, is transmitted by rod C to the lever D, which is held by spring E against edge F. The lower fork-shaped end of lever D is covering, more or less, two opposite

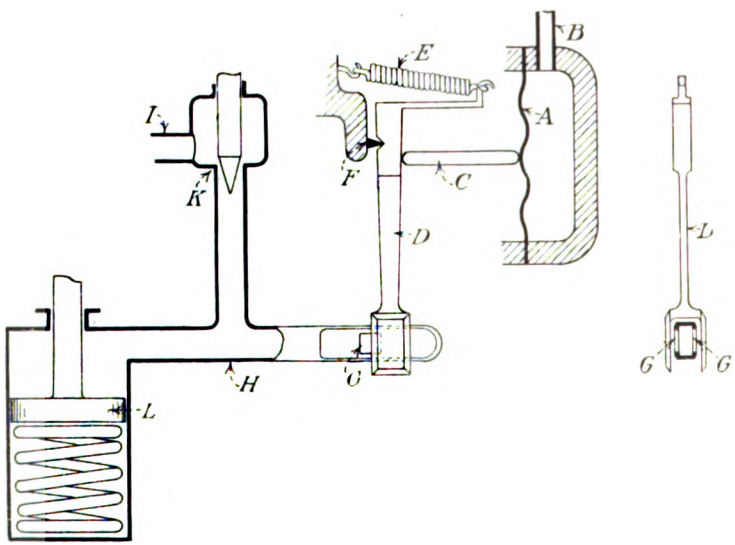

Fig. 7.—Principle of A.V.A. Pressure Relay.

orifices G in the oil pipe H. Oil is supplied by a small motor-driven pump under constant pressure through pipe I, and is throttled at K. A small movement of diaphragm A is magnified about 50 times by the lever D; this changes the size of the two orifices G, and hence the pressure in pipe H, resulting in a certain movement of the spring-loaded piston L. The success of this pressure relay is due not only to the steel diaphragm, but also to the arrangement of the fork D which is moving in a right angle to the oil jets through orifices G,

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so that fork D is perfectly balanced, and, further, to the absence of all friction in the entire relay.

The movement of piston L is used to control, by means of a pilot valve, the supply of pressure oil to a servo-motor actuating the regulating valve. Fig. 8 is a section through a complete regulating valve, which is equipped also with the return motion required for stability of regulation. The different parts of the relay are marked with the same letters as in Fig. 7.

These valves can be adjusted to regulate any steam pressure, and to keep such pressure constant within a range of less than one pound. The time required for opening and closing may be regulated between one-fifth of a second and 60 seconds. Further, these valves may be closed instantaneously by relieving the oil by turning the lever N, and after doing so the valve may be operated by the hand wheel shown on the top of the valve. All moving parts of the valve are working in a closed oil system, so that wear and need for attendance are practically negligible.

General Benefits from the System.

The most important advantage, and the one most difficult to appraise, is the beneficial effect of the system upon the quantity and quality of production. Just as constant voltage is an indispensable requirement in an electrical system, so constant steam-pressure and temperature are indispensable for uninterrupted production and uniform quality in the goods produced. The ability of the accumulator to deliver large quantities of steam at constant pressures is practically limited only by the size of the steam piping; the steam switchboard provides for automatic distribution.

It is an established fact that boiler efficiency over a considerable range of rating varies comparatively little, provided the tests are made during periods of constant operation, but the fact that efficiency during actual operation never equals

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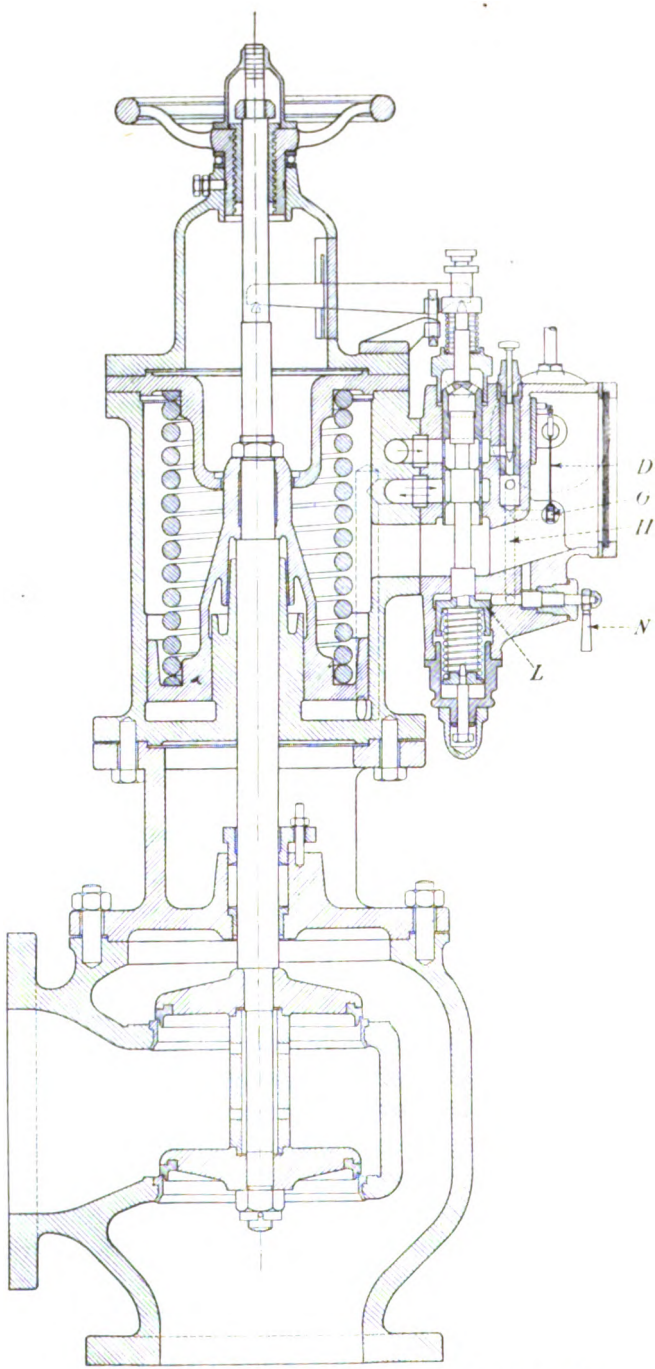

Fig. 8.—Section through A.V.A. Pressure-Regulating Valve.

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the test results has been confirmed by an increased boiler efficiency in plants which are equipped with accumulators. With an accumulator the boilers may operate continuously under the most favourable test conditions, and their operation is independent of that of the manufacturing plant and the power plant.

In plants where accumulators have been installed, savings in fuel of from 10 to 30 per cent. have been made.

With an accumulator, forcing the boilers will be avoided. Brickwork and boiler will be kept at an even temperature, and will be relieved of the constant expansion and contraction which accompanies a fluctuating load. This will reduce to a minimum the upkeep cost for boilers, furnaces, and firing equipment.

Since the operation of the accumulator installation is entirely automatic, and the operation of the boiler house and power plant is greatly simplified, a saving in labour operation costs will result.

Taking everything into consideration, both the capital and operating costs of a new steam-power plant will be considerably reduced if the steam accumulator system is adopted. On the other hand, if the accumulator is installed in an existing plant, the other savings, as analysed later, will pay for the installation in a short time.

The benefits of the steam accumulator system are dependent upon the conditions in the individual steam plant. A close analysis has to be made for each case. The best method to show the benefits is to describe some typical installations, but before doing this some general advantages may be pointed out.

The advantages of the accumulator for the manufacturing plant will be thoroughly discussed in Case 1, describing an installation in a textile mill.

The influence of the accumulator on the size and capacity of the boiler house and on the generation of power from process steam is shown in Case 2, a cane sugar refinery.

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The importance of the accumulator in steam plants which have a variable supply of fuel, for example, blast-furnace gas, wood refuse, surplus electric energy, etc., and the benefits of the accumulator with respect to fluctuating power loads in industries which are using little or no process steam, are both shown in Case 3, an iron and steel works installation. When hydro-electric power is transmitted over long distances, it is usually desirable to install local stand-by steam power stations, or lead storage batteries for use in emergencies. This is an important field for the use of steam accumulators, and an example of such an application is given in Case 4, a municipal electricity works at Malmö, Sweden.

Case 1. Application of the Ruths Accumulator to a Textile Mill.

Following is a description of an accumulator installation in a German textile mill. Before installing the accumulator the boiler house could not give sufficient steam, and an extension to it was considered. The total boiler capacity was 860 boiler h.p., in addition to which a locomobile of 150 h.p. was kept in operation. During the morning hours the pressure sometimes dropped so far that the heating up of dye kettles was considerably delayed, due to steam shortage; this in spite of the kettles being preheated for 1½ hour before the beginning of the working day.

The attendants were kept waiting until the proper temperature of the water could be reached. The arrangement of the steam plant before installation of the accumulator is shown in Fig. 9, and does not need further explanation. After careful investigation it was decided to install a steam accumulator, and the steam plant was rearranged as shown in Fig. 10.

When designing the accumulator installation, the steam consumption of the mill was measured as shown by the dotted line on diagram, Fig. 11. The fluctuations appear to be within

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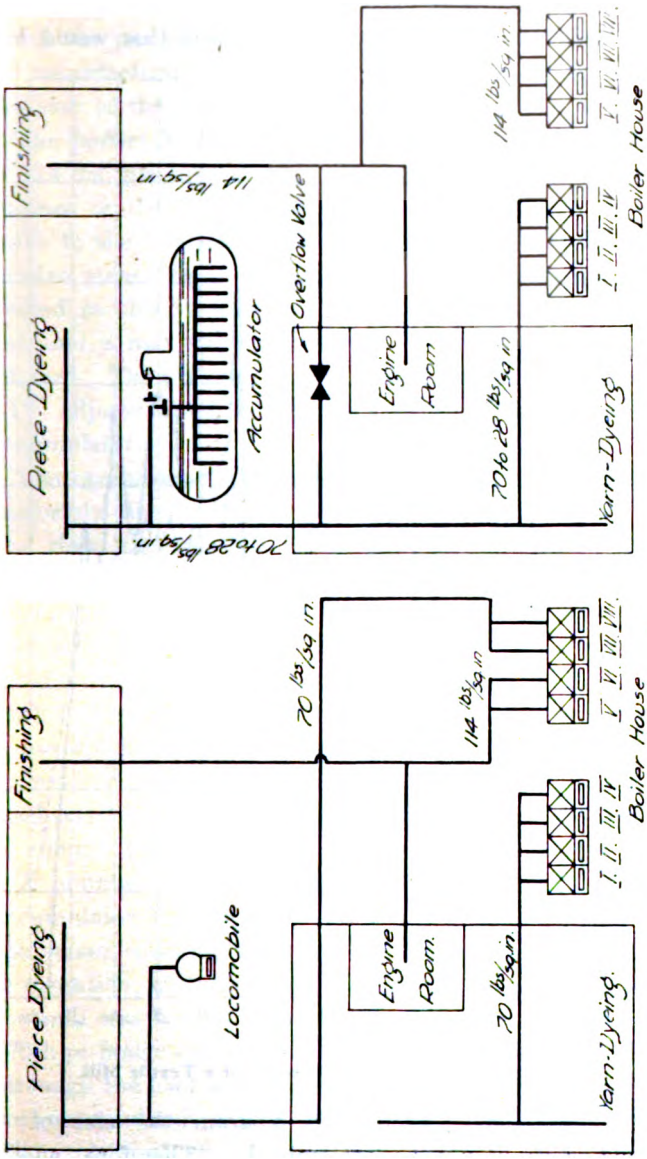

Fig. 9. Application of Steam Accumulator in a Textile Mill.

Fig. 10.

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reasonable limits. This, however, is simply due to the fact that the boiler is not able to cover a demand that would have

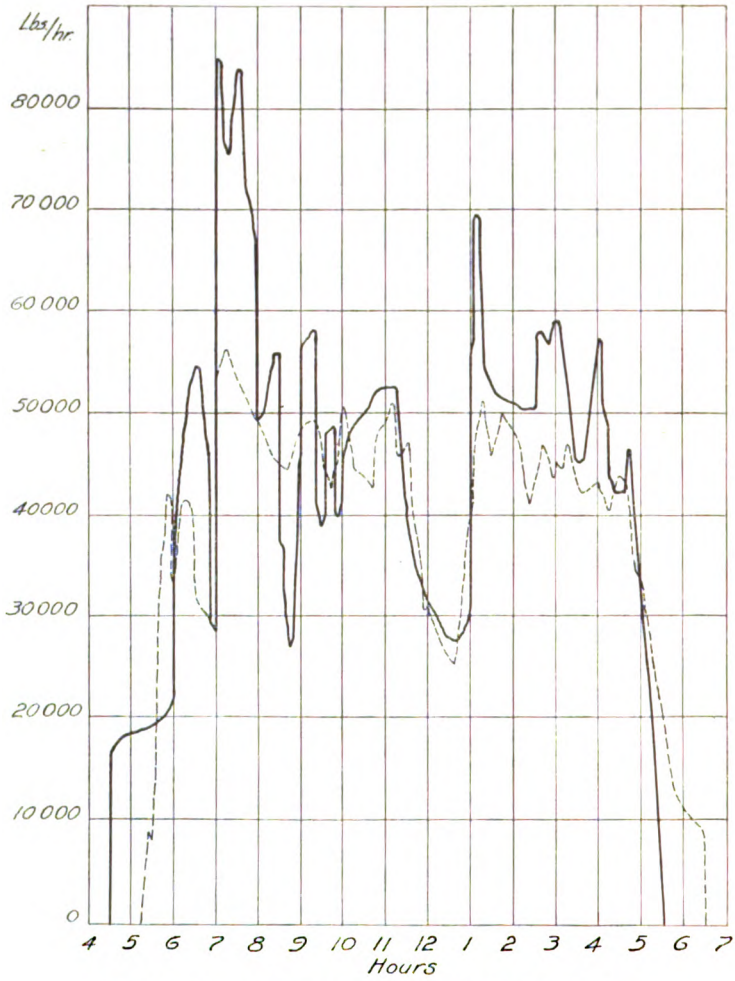

Fig. 11.—Steam Consumption Diagram for a Textile Mill.

greater fluctuations. From this diagram the size of the accumulator could not be determined. Therefore, another

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curve was calculated showing the probable steam demand when the processes were performed in the most suitable way for manufacturing and in the minimum time. From this curve the size of the accumulator was determined.

The boilers V-VIII are operated under a constant pressure of 114 lbs. per square inch. The steam not used by the steam engines or the finishing plant is passed through an overflow valve to the low-pressure steam lines. These steam lines also receive steam from boilers I-IV. The accumulator is connected to this steam line. Here a minimum pressure of 28 lbs. and a maximum pressure of 70 lbs. per square inch are allowed. The pressure in this piping system and in the boilers I-IV adjusts itself in accordance with the pressure in the accumulator.

The operation of the system is as follows:—All boilers are uniformly fired. If the steam consumption in the 114-lb. line rises, the overflow valve closes automatically, admitting the excess steam only to the dye-house lines. The same will happen if for some reason the steam generation in the high-pressure boiler decreases. The pressure will always remain constant at 114 lbs. per square inch, so that the steam engines work under full pressure. If a peak demand occurs in the dye house which cannot be covered by steam from the low-pressure boilers and the overflow valve alone, the accumulator will be discharged. If the steam consumption drops below the rate of supply, the accumulator will be charged.

A number of tests were made with and without the accumulator in this mill. In Fig. 11 the heavy line shows the steam consumption on a day when the accumulator was in operation, and the dotted line the steam consumption when the mill was run as before its installation. In the first case 770 h.p. boiler capacity was in service, in the latter 860 h.p., although the load was smaller. These curves demonstrate how the accumulator makes the steam consumption absolutely independent of the steam generation with respect to time;

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and this feature represents the most important point in the problem of storing steam. The management of the mill stated that the shortening of the time for heating up the dyeing kettles resulted in an increased output of not less than 10 per cent.; also an improvement in the quality of the product was stated, due to sufficient supply of steam of constant tempera-

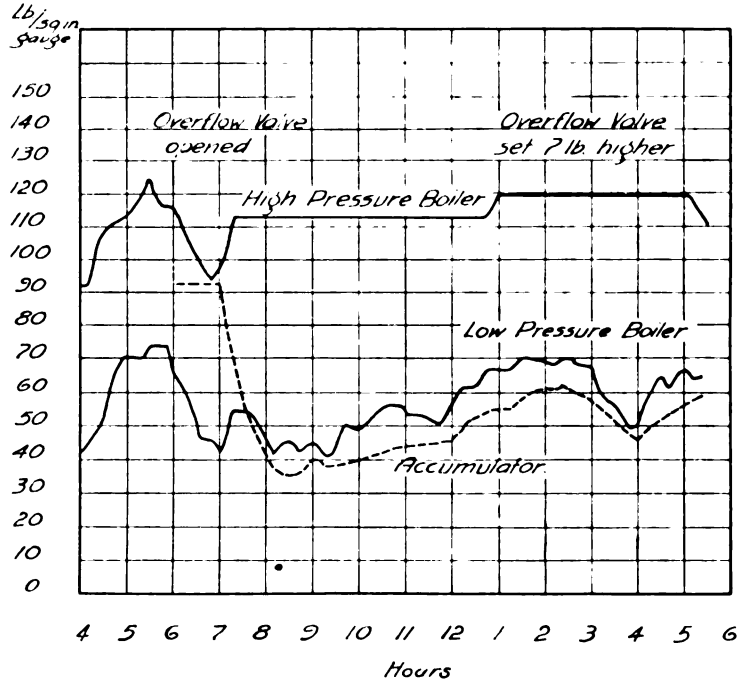

Fig. 12.—Pressure Diagram for a Textile Mill.

ture. In a mill equipped with an accumulator the required quantity of heat need not be generated for each instantaneous demand, but is available as stored heat ready to be used at any time. This is the secret of an unrestrained manufacturing process.

Fig. 12 shows the pressure conditions after installing the accumulator. The high pressure is maintained absolutely

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constant by means of the overflow valve, which made it possible to increase the output of the steam engines from 650 to 800 kw., and meant a reduction in purchased power of 150 kw.

The increased output from the factory is perhaps the most important feature of the Ruths accumulator, and needs some

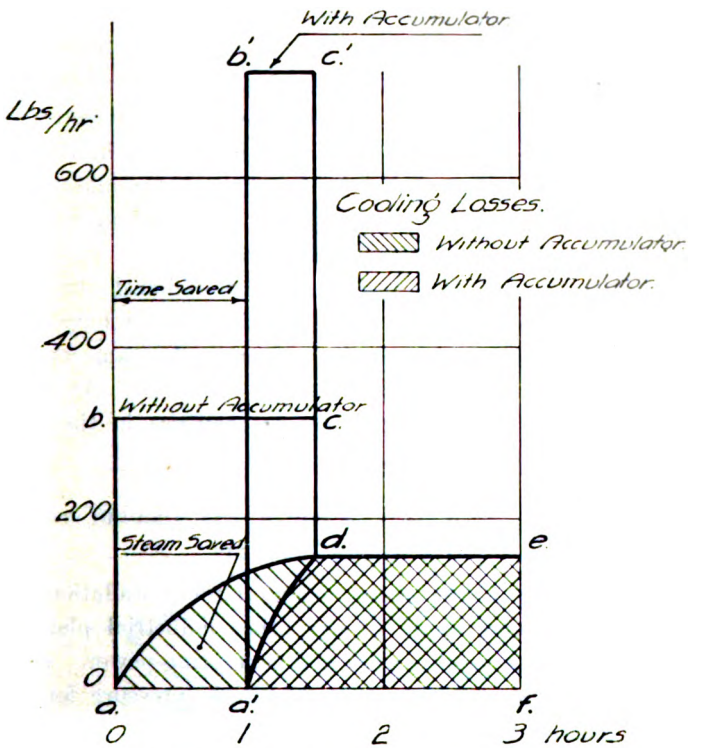

Fig. 13.—Steam Consumption Diagram for a Dye Kettle.

further explanation. As an example, I will describe the influence of the accumulator on the dyeing process. Fig. 13 shows the steam consumption of the dyeing kettle. Before the accumulator was installed, it took about 1½ hour to raise the temperature in the kettle to the boiling point. The steam

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required for this purpose corresponds to the surface *a b c d a*. During the starting up and after the boiling point is reached, steam must be supplied to the kettle to take care of the radiation losses correspondng to the surface *a d e f a*. After the installation of an accumulator, it was possible to start up the dyeing kettle to boiling point in 30 minutes without causing any trouble in the boiler house. The steam required for heating up corresponds to surface *a' b' c' d a'*, and the radiation losses to *a' d e f a'*. This diagram shows first that the time required for starting up the dyeing kettle has been reduced from 90 to 30 minutes. It may be mentioned in this connection that in many textile mills where accumulators have been installed the production has been increased up to 50 per cent. Further, it is to be seen that the radiation losses after the accumulator has been installed will be reduced corresponding to the surface *a d a' a*. Investigations made have shown that this, in many cases, means a decreased steam consumption in the dye house of from 10 to 20 per cent. At the top of the diagram is shown the temperature rise in the dyeing kettles with and without an accumulator.

Case 2. Application of the Ruths Accumulator to a Sugar Refinery.

The following Ruths steam accumulator installation for a sugar refinery may apply to any other industrial plant consuming steam for process work and generating power. Process steam is required in this plant at 15 lbs. pressure for triple effects, heating, etc., and at 90 lbs. pressure chiefly for the sugar pans. The entire consumption of steam is shown in Fig. 14. The demand for steam is changing constantly and within short periods through a wide range. The steam consumption averages 125,000 lbs. per hour, and fluctuates between 70,000 and 180,000 lbs. per hour. The demand for power of the entire refinery is fairly constant, and amounts to about 2,000 kw.

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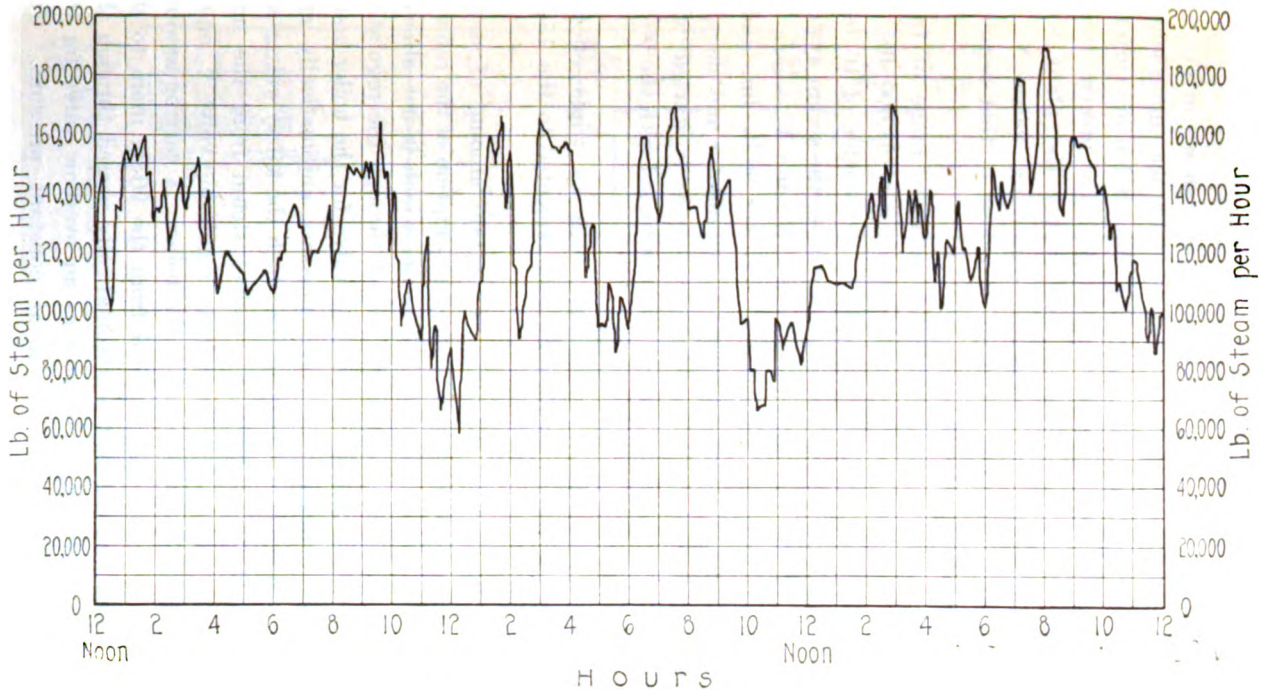

Fig. 14.—Steam Consumption in a Sugar Refinery.

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The layout of the proposed installation is shown in Fig. 15. The boilers are designed for a pressure of 300 lbs. and a superheat of 150 degrees F. Two 1,000-kw. non-condensing turbines equipped with speed governors will expand the process steam from 300 to 90 lbs. pressure, and supply the plant with electrical current. A compound regulating valve V_1 is arranged to by-pass process steam in excess of that required for the generation of power.

The accumulator works through a pressure range of from 90 to 15 lbs., and has a storage capacity of 54,000 lbs. of steam, a volume of 12,000 cubic feet, a diameter of 16 feet, a total length of 66 feet, and is connected to the steam system by means of the two regulating valves, V_2 and V_3.

The sugar pans are connected to both the 90-lb. line and a special line directly connected to the accumulator and carrying accumulator pressure. The cooking process is started with steam from the accumulator line, and continued with the 90-lb. steam pressure.

All the other steam consumers, such as triple effects, evaporators, heating system, etc., are connected to the 15-lb. steam main.

In the operation of the plant, a constant amount of steam corresponding to the average steam consumption of the refinery is generated in the boilers. All steam which is not allowed to pass through the turbines is passed through the regulating valve V_1, which acts as an overflow valve for the boiler-house main, and maintains the boiler pressure automatically and constantly just below the point for which the safety valves are set. The 90-lb. steam main receives steam from the non-condensing turbines and through the regulating valve V_1 equal to the constant steam-output of the boiler. A varying amount of steam as required is supplied from the 90-lb. main to the sugar pans, and the rest is automatically passed through the regulating valve V_2, which acts as an overflow valve for the 90-lb. main and maintains it at constant pressure. The

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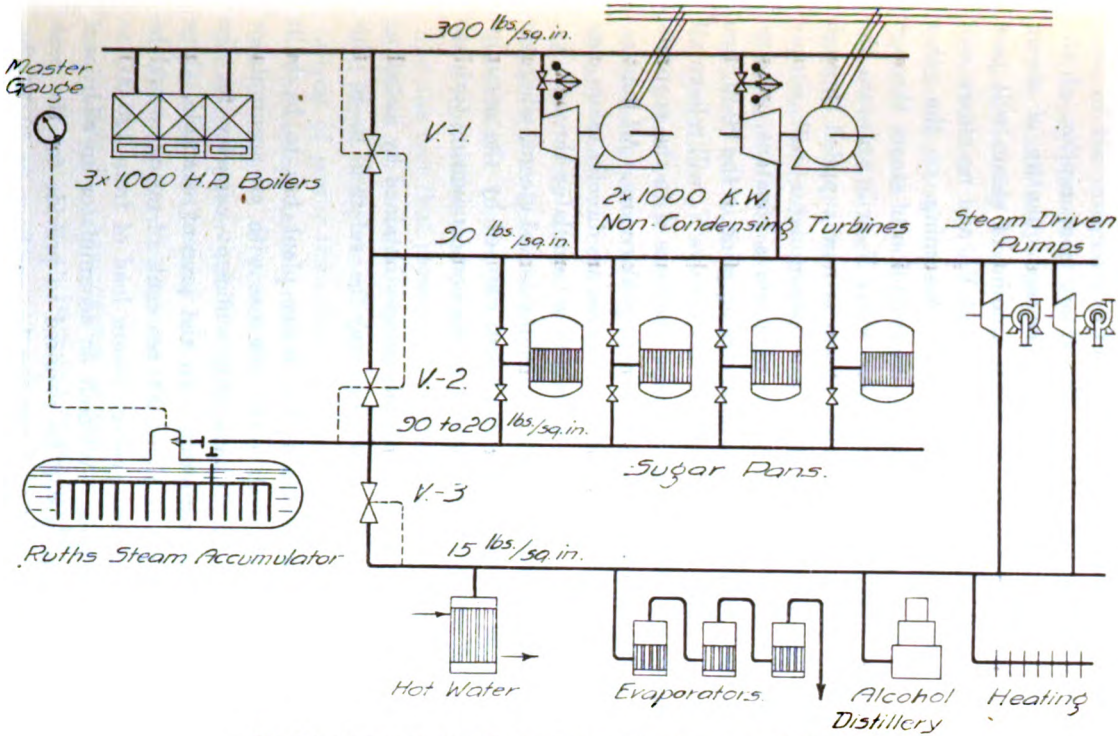

Fig. 15.—Arrangement of Ruths Accumulator in a Sugar Refinery.

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reducing valve V_2 admits enough steam to the low-pressure main to maintain 15 lbs. pressure in it.

If, at a certain moment, the steam consumption of the refinery corresponds to the total average quantity of steam supplied by the boilers, an equal amount of steam will pass through both regulating valves V_2 and V_3, and no steam will pass to or from the accumulator. Assuming, on the other hand, that a peak occurs in the consumption of steam through the 90-lb. main to the sugar pans, valve V_2 will maintain the 90-lb. pressure, and since less steam is now supplied through it to the low-pressure line, the accumulator will supply sufficient steam through V_3 to maintain a constant pressure in the 15-lb. main. If the steam consumption in the 90-lb. line again decreases, or even drops to zero, valve V_2 will relieve all excess steam from the 90-lb. main and pass it to the accumulator, where it is stored until the next peak occurs. All fluctuations in the consumption of 15-lb. steam are directly taken care of by a variable discharge from the accumulator through V_3.

Thus all fluctuations in the consumption of steam, wherever they occur, are automatically taken care of by the accumulator, and will not be felt either at the non-condensing turbines or in the boiler house.

In addition to the general advantages obtained by installing an accumulator, the following may be referred to in this special case.

Without an accumulator the boiler plant has to be built to provide for the peak loads, whereas with an accumulator the boiler plant need have only sufficient capacity for the average steam consumption. In the present example, three boilers of 700 h.p., at about 200 per cent. of rating, would be able to cope with the average steam load of from 120,000 to 130,000 lbs. per hour. Without an accumulator an additional boiler of 700 h.p. would be required to provide for the peak loads, which go as high as 180,000 lbs. per hour, or 50,000 lbs. per hour above the average. The saving in cost for a com-

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pletely equipped boiler of 700 h.p. will more than pay for the cost of the installation of the entire accumulator system.

During periods of low steam-consumption, when sufficient power could not be obtained from the process steam in the non-condensing turbines, it would be necessary without an accumulator to install bleeder turbines instead of non-condensing turbines, so that with decreasing consumption of process steam the deficiency in the output of non-condensing power could be made up in the low-pressure stage of the bleeder turbine. Not only would the additional cost of the bleeder turbine with low-pressure stage, condenser, and condenser pumps be considerably more than the cost of non-condensing turbines, but such a plant would be much more complicated in operation.

Further, with an accumulator the output of cheap non-condensing power will be increased. Without an accumulator steam would at certain times have to by-pass the turbines, and at other times not enough process steam would be consumed to generate sufficient power in the turbines. The accumulator makes it possible to pass all the process steam as a continuous and constant flow through the turbines. This, and the fact that pressure and superheat at the throttle of the turbines are constantly being maintained at their highest point, will result in highest efficiency of the turbines and in maximum output of power from the process steam.

The saving, as compared with hydro-electric power previously used, amounts to about £16,000 per year, and the cost for generating power out of the process steam amounts to only 6 per cent. of the total fuel cost, plus depreciation and upkeep of the necessary equipment.

Case 3. Application of the Ruths Accumulator to an Iron and Steel Works.

A somewhat different problem has to be solved for the application of the accumulator system to power stations for

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industries which are chiefly consuming power and using little or no steam for process work. Here the accumulator has to

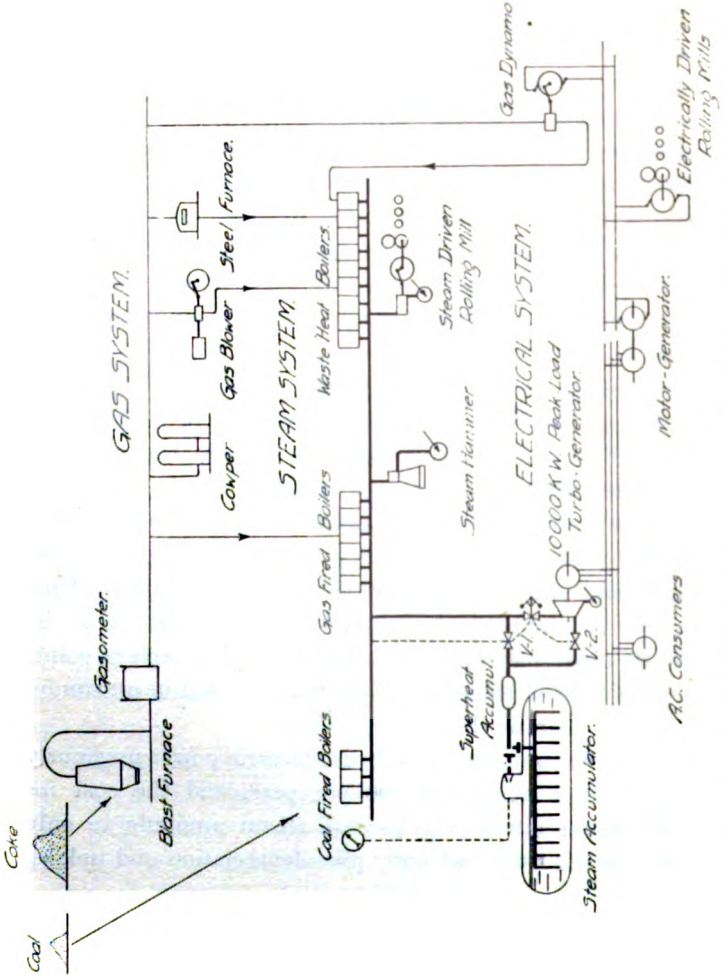

Fig. 16.—Arrangement of Ruths Accumulator in an Iron and Steel Works.

deliver steam to the turbines. The accumulator, as described above, delivers dry saturated steam, whereas it is desirable

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that the steam delivered to steam turbines be superheated. This problem has been solved by adding, in series with the ordinary accumulator, a second accumulator for storing the superheat. This superheat accumulator works on the same principle as the well-known Siemens regenerative heater, and for the superheat storing medium uses cast-iron plates.

The connection of an accumulator either to the first stage or to an intermediate stage of a steam turbine will not affect the overall efficiency of the turbine. A small loss of power, due to a certain pressure drop in the comparatively small amounts of steam passing through the accumulator, is counterbalanced by an increased efficiency, due to the pressure and superheat at the turbine throttle being constantly maintained at the highest possible point.

An installation of this kind which has been proposed for an iron and steel works is shown diagrammatically in Fig. 16.

The energy required in the entire iron and steel works is supplied mainly by the coke with which the blast furnaces are charged. A comparatively small amount of coke gas is used in the steel furnaces, and only a few per cent. of the total energy is supplied by coal-fired steam boilers.

Three blast furnaces are operated, with an output of approximately 1,500 gross tons per 24 hours. In the blast-furnace gas is contained about 63 per cent. of the heat supplied with the coke. This gas is used primarily in the cowpers for preheating the air required for the blast furnaces, in steel furnaces, in gas engines producing about 7,500 kw. for driving air blowers, and in another group of gas engines coupled with direct-current generators and generating about 12,000 kw. After all these consumers are satisfied, the remaining surplus of blast-furnace gas is used in gas-fired boilers for the generation of steam. Large amounts of steam are also obtained indirectly by recovering waste heat from steel furnaces, air blowers, and gas dynamos.

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This steam energy is in turn converted into mechanical energy in steam hammers and in steam engines driving rolling mills, and another part is converted in alternating current turbo-generators into electrical energy. The alternating- and direct-current lines are connected by means of motor-generator sets. The largest consumers of electrical energy are electrically-driven rolling mills. Obviously, part of the energy supplied with the coke is transformed into several different forms before it is finally applied and allowed to waste, and an interruption of the flow of energy in one department will necessarily affect many other departments, so that waste of energy, loss of production, or both will result.

However, large fluctuations, which cannot be prevented, occur in the production of blast-furnace gas and in the consumption of energy. There are also fluctuations in the consumption of steam in 24 hours, caused by the rolling mills, steam hammers, presses, etc., as shown in the lower curve of Fig. 17. The average consumption is about 125,000 lbs. per hour; and a minimum of 30,000 may be followed immediately by a maximum of 200,000 lbs. per hour. Due to variations in supply and demand of steam, a large coal-fired boiler house has been provided for the purpose of equalisation, but the fluctuations are of such magnitude and occur so suddenly that operating conditions are extremely difficult, and it has been estimated that about 15 per cent. of the blast-furnace gas has to be wasted, due to the difference existing between supply and demand. Further, careful tests have shown that the efficiency of the gas- and coal-fired boilers under actual operating conditions is about 55 per cent., whereas an efficiency of 76 per cent. was obtained with tests during which the boilers were fired at a constant rating. This would mean a saving in fuel of 27·6 per cent.

Another difficulty is caused by the varying demand for electrical energy shown by the upper curve in Fig. 17. The average demand is approximately 16,000 kw., with fluctuations

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going 4,000 kw. below and above this amount. About 12,000 kw. on the average is supplied by the gas engine, and the rest,

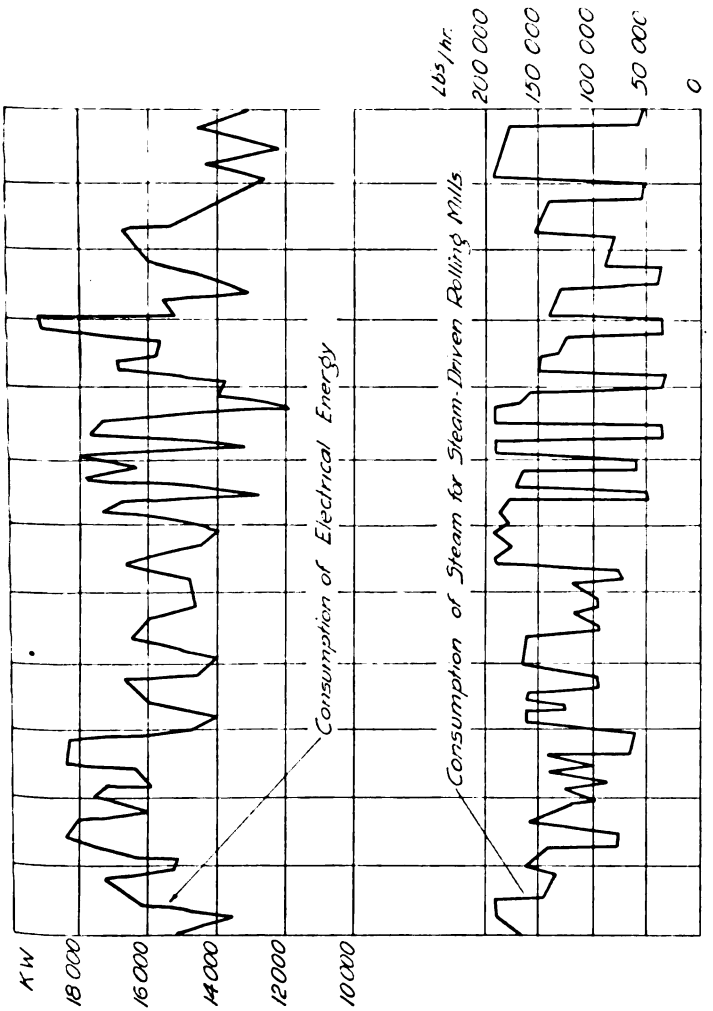

Fig. 17.—Steam and Power Consumption of an Iron and Steel Works.

or about 4,000 kw., is generated in turbo-generators. Since it is difficult to regulate the load of gas engines in wide limits,

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it is desirable to take as much as possible of the fluctuations with the steam turbines. This, on the other hand, increases the difficulties in the steam system which have been described above.

From the foregoing it will be understood that very large savings and improvements in operation and increase of production would be obtained with a system allowing continuous operation at constant ratings of the gas engines, the coal- and gas-fired boilers, and the waste-heat boilers, and one which would take care of excess energy during periods of large supply and low consumption, and would continuously secure an abundant supply of steam and electrical energy.

This is made possible with the Ruths accumulator installation, which consists of two Ruths accumulators, one superheat accumulator, and a 10,000-kw. peak-load turbine. This system is capable of storing an amount of energy contained in 60,000 lbs. of steam, and it can deliver this energy in the form of an electrical peak-load of 4,000 kw. per hour. The two steam accumulators each have a volume of 6,500 cubic feet, a diameter of 12 feet, and a total length of 60 feet. The superheat accumulator has a volume of 1,000 cubic feet, a diameter of 6 feet, a length of 35 feet, and contains 300,000 lbs. of cast iron.

The accumulators and turbine are connected, in the way shown in Fig. 16, to a steam main carrying a pressure of 200 lbs. and connecting the boiler plants with each other. An excess of steam in this main will cause the regulating valve V_1, which works as an overflow valve for the 200 lbs. pressure, to open. The surplus of steam will then first pass to the superheat accumulator, where the superheat is stored, and saturated steam will be passed on and stored in the steam accumulators. On the other hand, with a low supply of steam or large consumption of electrical energy, the regulating valve V_1 will close, and the speed governor of the turbine will first admit

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all of the available live steam to the turbine, and then will open valve V_2. Steam will be discharged from the accumulator, superheated while passing through the superheated accumulator, and admitted through valve V_2 to the turbine. The accumulators are designed to work in the pressure range from 200 to 60 lbs., and the steam from the accumulators will, therefore, be admitted by valve V_2 to a later stage of the turbine than the live steam, which simultaneously is admitted to the first stage of the turbine.

This system will take care of all the steam supplied by the waste-heat and gas-fired steam boilers, it will automatically maintain a constant pressure of 200 lbs. in the steam main, and it will keep sufficient steam back in this line for the demands of the steam-driven rolling mills, steam hammers, etc. The accumulator system will further allow the gas engines to operate at a constant and economical load, producing about 12,000 kw. The peak-load turbine will, with the accumulators, take over the rest of the electrical load, which varies from 1,000 up to 9,000 kw. The coal-fired boilers may be fired at a constant rating. Their load will only have to be changed in case the accumulator pressure, which is indicated in the boiler house by a master gauge, tends to reach its upper or lower limit, and such occasional changes may further be effected gradually.

The accumulator installation will pay for itself in a short time by the savings effected and the general advantages obtained. It will take care of peak loads up to 4,000 kw. above the average consumption, and replace a corresponding amount of boiler-house capacity. It will do away with most of the wastes of the gas- and coal-fired boilers and the gas engines, and will allow boilers and gas engines to operate at constant rating and highest efficiency. It will act as a fly-wheel for the entire works, allowing continuous and uniform production by taking up automatically excess energy and supplying it again during peak loads.

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Case 4. Application of the Ruths Steam Accumulator System as Stand-By for Hydro-Electric Power Plant.

The following example shows how the accumulator system can be designed to suit the most diverse requirements:—

At the municipal electric power plant at Malmö, Sweden, the question of a stand-by plant for steam was a serious problem. The city purchases hydro-electric power delivered over a long transmission line. Due to frequent disturbances, a stand-by was required capable of carrying at least the electric load for lighting and street railways. For this purpose a large lead storage battery was installed originally, and, further, some of the boilers in the steam plant were always kept under pressure. So as to save the cost of keeping the boilers under pressure, a Ruths steam accumulator was installed, as shown diagrammatically in Fig. 18.

Two accumulators of 8,000 cubic feet volume each, with a capacity (together) of 80,000 lbs. of steam, on a pressure drop of 114 to 28 lbs. per square inch, are used. These accumulators are kept under pressure, the cooling losses being taken care of by a small electric boiler. Further, a specially designed condensing steam turbo-generator of 3,750 kw. has been installed. The generator end of this unit normally runs as a synchronous condenser, but as soon as a break occurs in the supply of hydro-electric power, the speed governor on the turbine opens a valve V_2, admitting steam from the accumulator to the turbine. The load will thus be instantly carried by the steam turbine, and no disturbances will be felt in the supply of electric energy for lighting and street cars. In order to maintain the highest efficiency on the turbine, the steam from the accumulator is passed through the first stage until the pressure drops to 67 lbs. per square inch. At this pressure the steam is by-passed the first stage, and enters the second stage direct until the pressure drops to 42 lbs., when the steam is entered direct to the low-pressure stage. The

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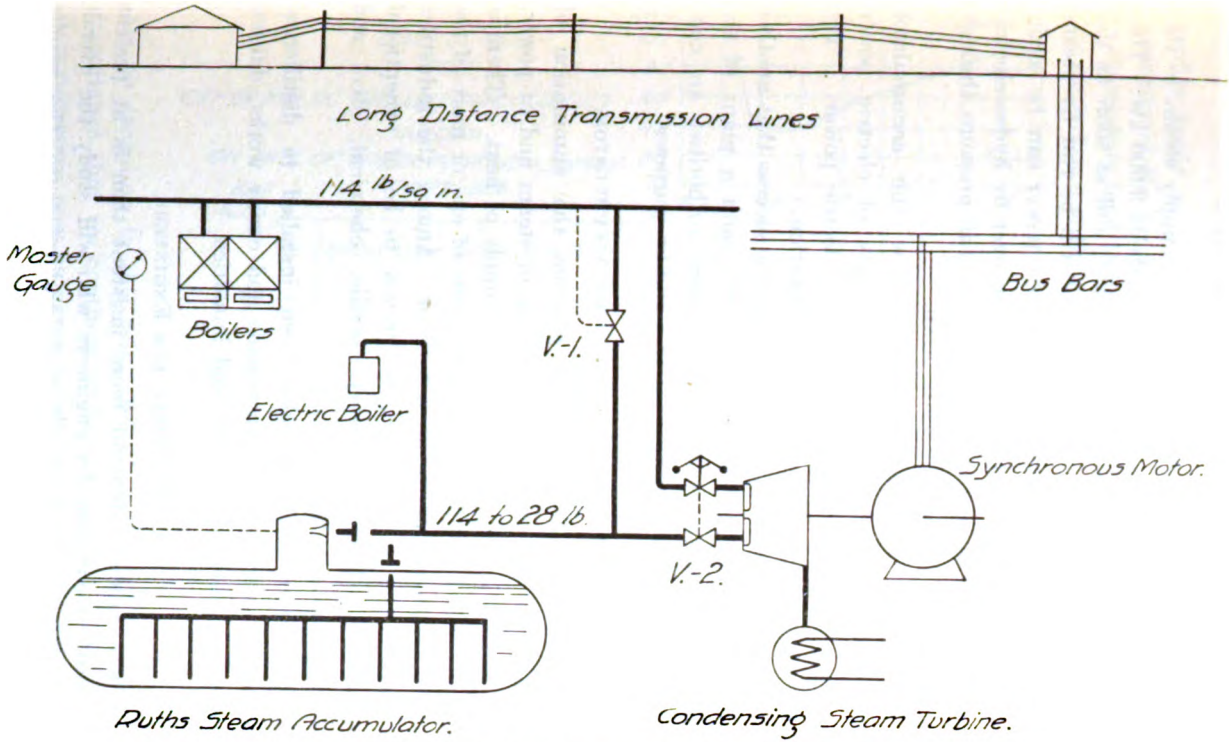

Fig. 18.—Electric Stand-by Plant, Malmö, Sweden.

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accumulator installation is big enough to supply steam to the turbine for about one hour, developing about 3,000 kw. This is sufficient time to start the boiler plant, and as soon as the boiler pressure is obtained, the turbine will be run by steam from the boilers until the hydro-electric power can be again supplied. As soon as the load is taken over by hydro-electric power and the accumulator is charged to full pressure through valve V_1, the boilers are shut down.

Fig. 19 shows diagrammatically how the accumulator installation ensured a continuous supply of electric power during a break in the supply of hydro-electric power. The diagram hardly requires further explanation.

This installation has proved to be such a success that another municipal power station in Sweden has built a plant of the same type, and many other power plant authorities are considering similar arrangements for stand-by purposes.

Field of Application for the Accumulator.

The accumulator has made possible the elimination of variations in the rate of consumption of steam and of power, and elimination of variations in the supply of heat. There is practically no industry where variations of one or more of the kinds mentioned above do not occur. Among the industries in which the accumulator has proved to be of exceptional value are:—Pulp and paper, textile, chemical, steel and mining, rubber, and sugar.

The accumulator has also been installed in distilleries, breweries, starch mills, marmalade and candy works, dairies, tanneries, hospitals, hotels, and laundries.

A New Field for Engineers.

There exists a demand more insistent than is at present generally recognised for engineers who will study the overall steam economy of the factory and measure the results obtained, not in terms of steam-plant efficiency alone but in

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profits made as a result of an increase in the quality and quantity of the product produced.

Specialists tend to become one-sided and often to exaggerate the importance of their special subject. Engineering specialists

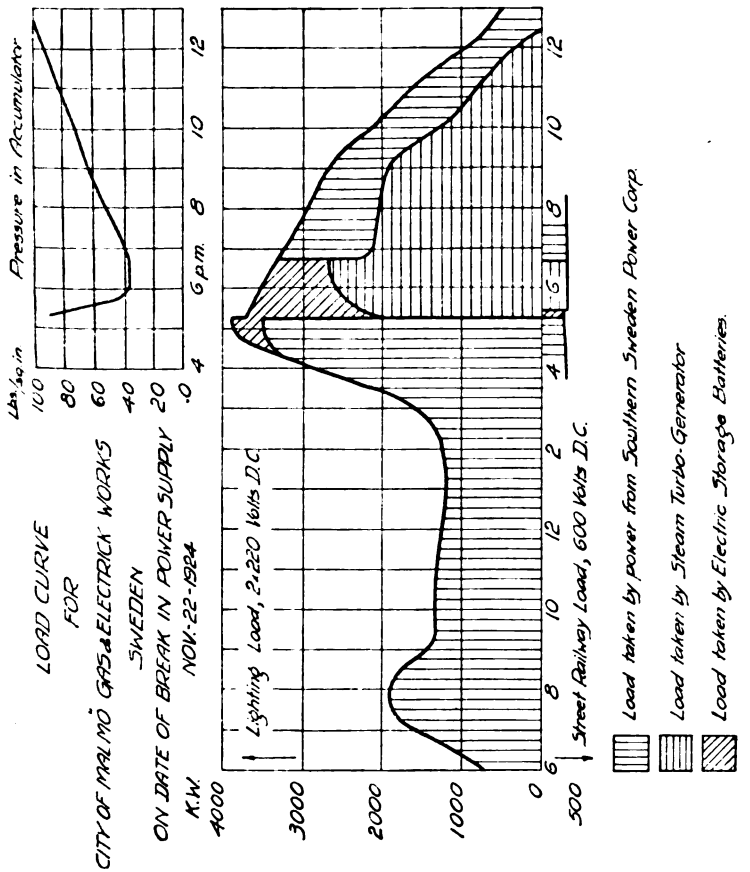

Fig. 19.

are no exception to this rule, and while it is of the utmost importance that we continue to have specialists in all fields, it is necessary now as never before to develop engineers who will study broadly the application of steam to industry,

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particularly in its ultimate effect on the cost and quality of the articles produced. This is a field of study essential to our national welfare. We cannot afford to neglect anything that will tend to increase the overall economy of our industrial plants. I write now especially of what may be termed heat-using industries, textile, chemical, sugar, and paper plants. Very few of these industries, for instance, should purchase outside power. Their power requirements should be supplied as a by-product of the steam required for processing.

Through combustion specialists we know how to produce cheap steam. Coal is being burned in powdered form at some plants with a monthly efficiency of 92 per cent. The next step will be the carbonisation of coal before it is burned, and it is felt that along the lines of boiler-room efficiencies, in so far as they are effected by coal-burning equipment, we are fast approaching the limit.

It is not sufficient, however, merely to produce cheap steam. We must be sure that we are not using a single additional pound of this cheap steam beyond what is actually required, and it is in the economy in the use of steam after it is produced that the greatest savings in industry will be effected. This is the largest field for the accumulator, and its development is intimately bound up with the study of exhaust steam engineering. If the importance of this subject be doubted, reference should be made to two excellent World Power Conference papers, one entitled "German Practice in Exhaust Steam Engineering," by H. Treitel, from which I quote as follows:—

The Mental Powers Furthering the Development of Exhaust Steam Engineering.

"In Germany the development was brought about by the large electrical and mechanical manufacturers. These firms were the advisers and instructors of the industry, including electricity supply concerns, on all questions relating to heat

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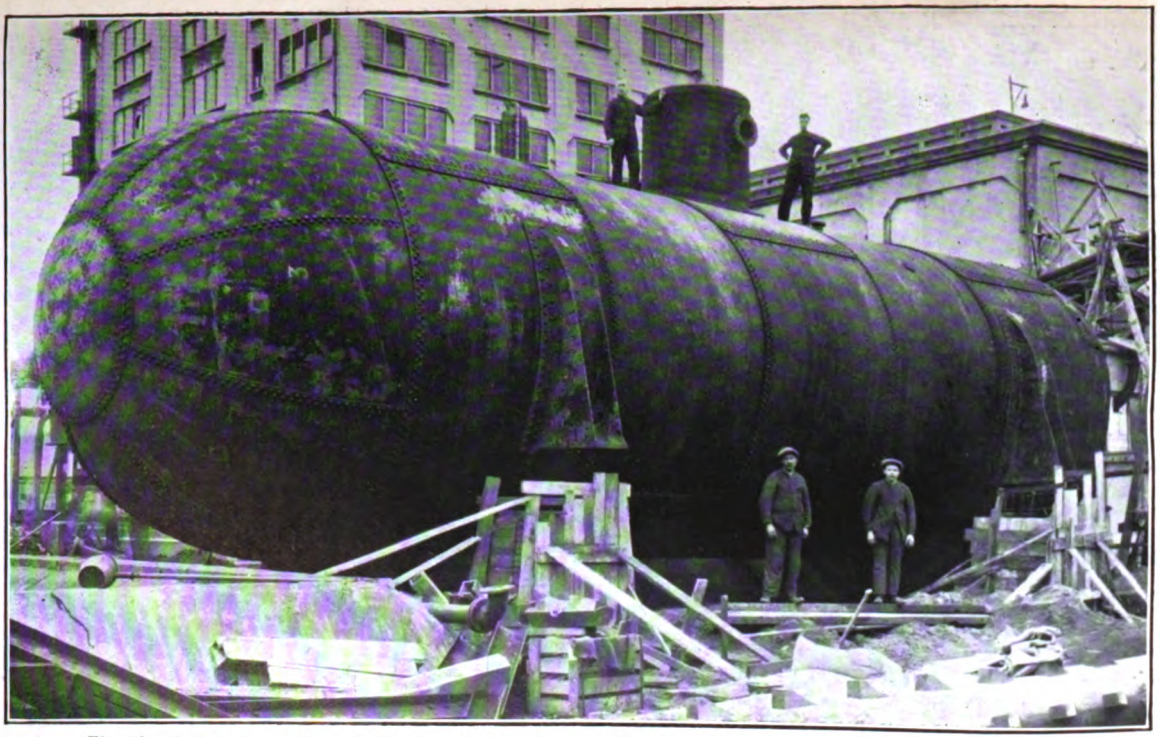

Fig. 20.—Cellulose and Paper Mills, Von Golder Zonen, Holland. Accumulator Tank in course of erection. Volume, 11,300 cubic feet.

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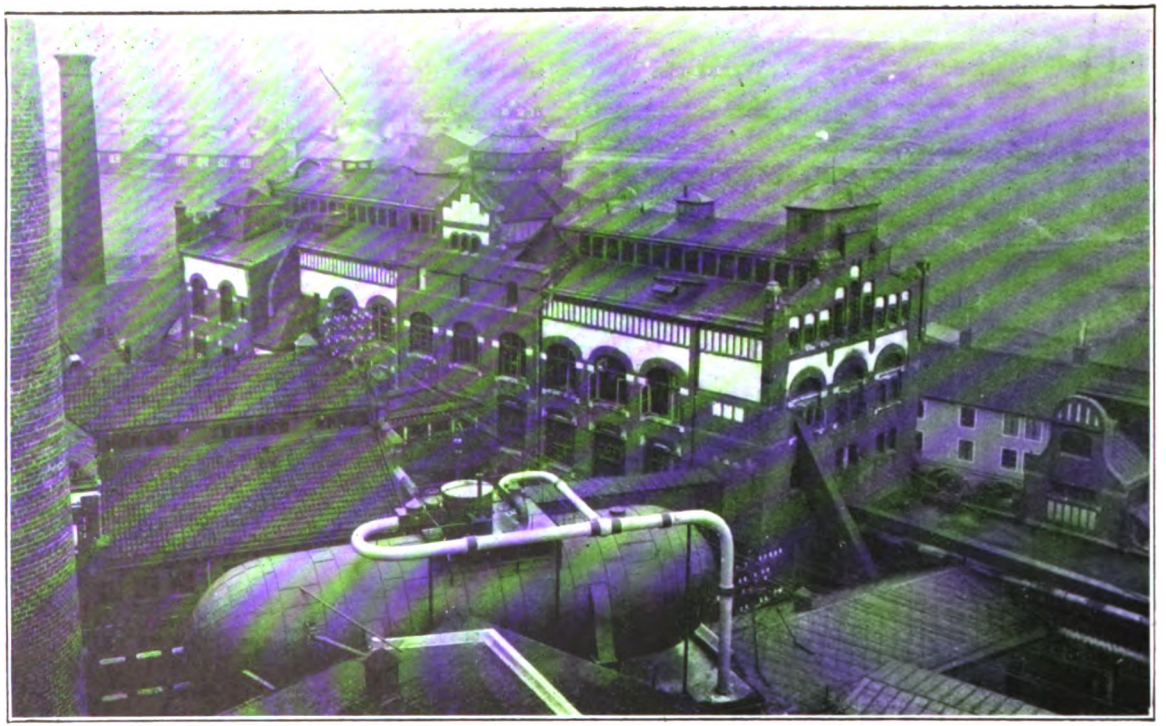

Fig. 21.—Ruths Accumulator in Carnegie Sugar Factory, Sweden. Volume, 11,700 cubic feet.

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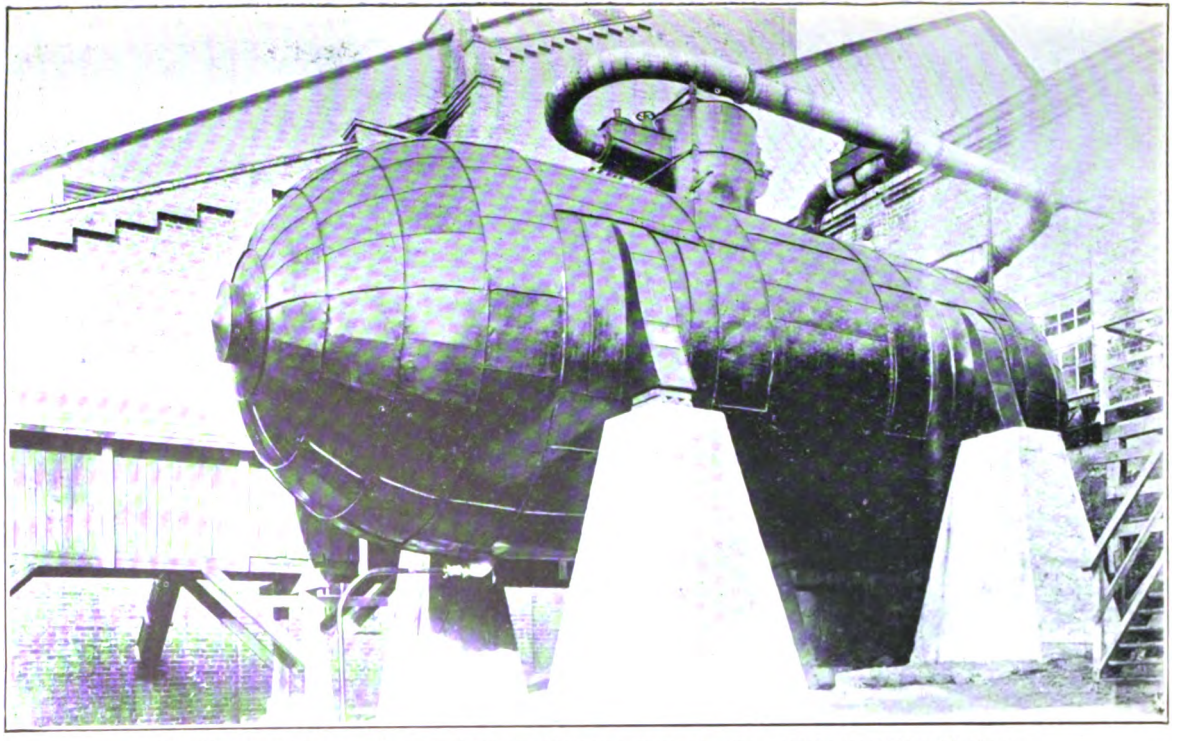

F'g. 22.—Ruths Accumulator in Nyhamn Cellulosa A.B., Sweden. Volume, 4,400 cubic feet.

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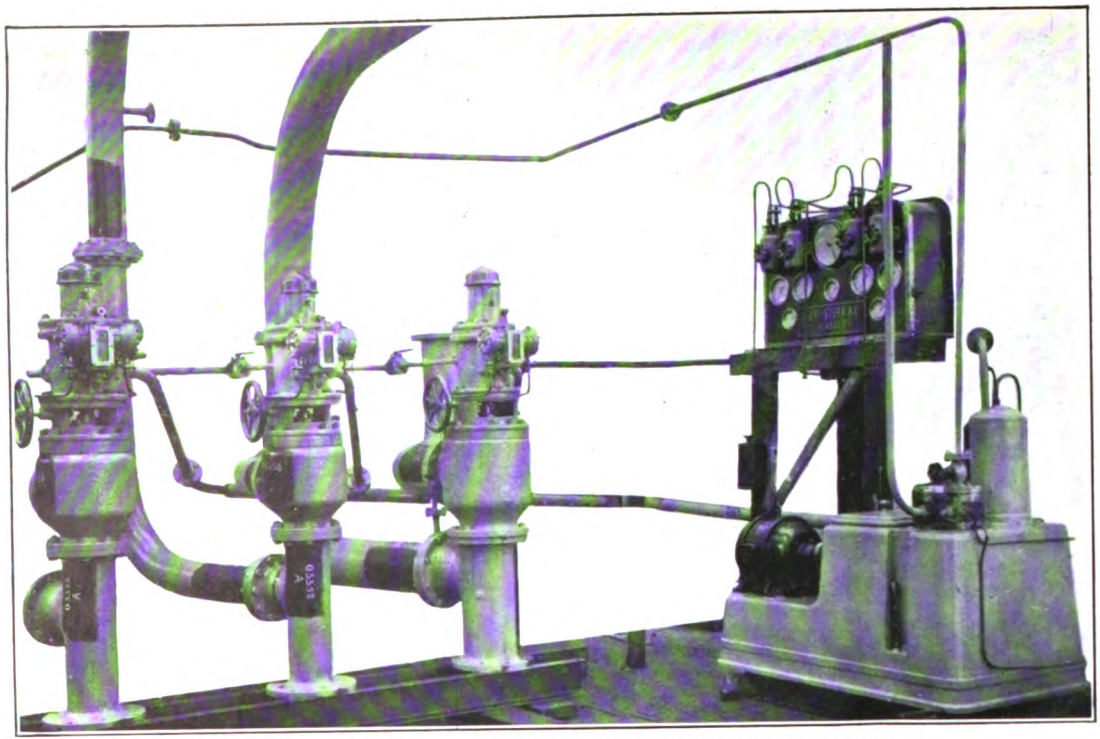

Fig. 23.—Steam Switchboard for Ruths Accumulator, Van Gelder Zonen, Holland.

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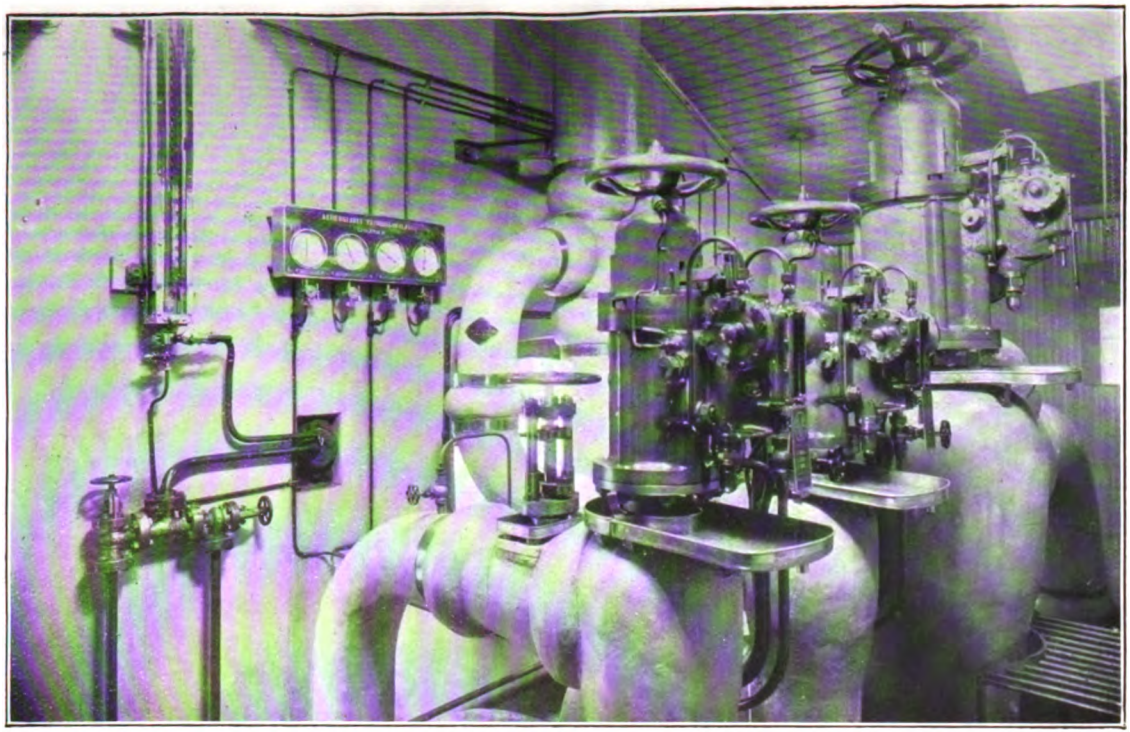

Fig. 24—Steam Switchboard for Ruths Accumulator, Kilsund Bros. Textile Mills, Sweden.

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engineering. In other countries it is considered the duty of the independent consulting engineer to solve the engineering and economical problems. In Germany the manufacturers have become accustomed critically to study the technical and economical requirements of clients. The choice of machines, the connections and regulation of steam circuits, are becoming more and more complicated, especially when boilers working at different pressures and governed accumulators are introduced. There are but few clients that are able to give accurate data on the demand for steam and power over a given time. When preparing propositions, the contractors must, therefore, make their own careful measurements of the steam produced and consumed at each point on typical days. In several instances turbine manufacturers undertook to build the complete industrial power station with the entire complicated plant for the economical use of exhaust steam.

It is only a few years ago that large industrial concerns commenced to engage their own specialist for heat economy. To-day, even small industrial combines, such as those for brickworks and potteries, glass works, and lime production, have organised their own departments for dealing with these questions; they exert a valuable and instructive influence by spreading experience gained in other quarters. It is not likely that, even in small works with a purely commercial management, any departure from commonly approved principles as to efficient exhaust steam economy will escape their notice."

The other World Power Conference paper is "The Reciprocal Utilisation of Waste Energy," by Oberbaurat Ing. Bernhard Moritz Gerbel, in which this appears:—

"The reason why the utilisation of waste heat in steam plants has, up till now, not assumed larger dimensions is that the leaders of large industries, the managers, and other competent persons are interested only in the progress of heat-technics so far as their own plant is concerned. In cases where, in their own plant, steam is required not only for the

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generation of power but also for boiling, heating, or drying purposes, a combination as before mentioned must be considered and introduced, as the saving of coal effected by these combinations is a sufficient motive. But plants requiring power alone generally only produce this power out of coal, and the great losses of heat are accepted as unavoidable, *i.e.*, immense quantities of hot water are allowed to run unused into the drains. The utilisation of this waste heat beyond their own plant is generally not thought of, whereas the possibility of developing the utilisation of waste heat is founded especially on its employment outside their own plant, a combination which would be extremely economical for the various plants and of greatest importance for political economy.

The future development of the utilisation of waste heat does, therefore, not only depend on the combination of the generation of power with the employment of waste heat for boiling and other purposes within the reach of one and the same plant, but on the co-operation of different plants for the purpose of the utmost joint utilisation of their fuel."

The Ruths accumulator system affects fundamentally the whole steam economy of the plant in which it is installed. The accumulator can be used not only to supply steam for peak loads and thus completely equalise the generation of steam, but it may be used to store in the form of steam the large quantities of excess heat (available in the form of exhaust steam, hot exhaust gases, excess electric current, etc.) which are found in certain industries. The subject is now being extensively studied in Europe, and is one that is equally essential to the benefit of our own industries.

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RUTHS STEAM ACCUMULATOR SYSTEMS.

No.	Purchaser.	Country.	Industry.	Ordered	Accumulator. Volume.	Capacity.	Pressure.
					Cubic Feet.	Lbs. of Steam.	Lbs. per Sq. Inch.
1	Holmens Bruks & Fabriks A/B, Hallstavik	Sweden	Pulp & Paper	1916	3,000	12,500	85-22
2	Sockerfabriks A/B, Göteborg	,,	Sugar	1917	6,500	34,200	156-28
3	Stockholms Benmjölsfabriks A/B	,,	Bone Meal	1917	2,000	7,000	64-14
4	Sandvikens Järnverks A/B	,,	Iron & Steel	1918	3,500	8,800	130-57
5	A/B Kaukas Fabrik, Joutseno	Finland	Pulp & Paper	1918	6,000	7,700	37-21
6	A/B Kaukas Fabrik, Kaukas	,,	,,	1918	12,200	26,500	34-10
7	Vargöns A/B, Vargön	Sweden	,,	1918	3,900	12,500	75-21
8	A/B Gutzeit & Co., Kotka	Finland	,,	1919	11,300	19,800 13,200	30-11 23-11
9	O/Y Rauma Wood Ltd.	,,	,,	1919	4,400	17,600	80-14
10	A/B W. Rosenlew & Co.	,,	,,	1919	9,700	40,600	87-15
11	J. H. Munktells Pappersfabriks A/B, Grycksbo	Sweden	,,	1919	5,300	16,500	100-35
12	A/B Edsvalla Bruks, Edsvalla	,,	,,	1919	4,400	15,400	85-25
13	A/B Liljeholmens Stearinfabrik, Stockholm	,,	Candle Factory	1919	2,650	4,100	71-43
14	Billeruds A/B, Billerud Sulphite Pulp Mill, Säffle	,,	Pulp & Paper	1919	3,000	10,000	85-24
15	Billeruds A/B, Slottsbron	,,	,,	1919	3,000	10,000	85-24
16	J. H. Munktells, Grycksbo	,,	,,	1919	5,300	16,500	35-71
17	Enso A/B, Enso	Finland	,,	1919	9,200	40,000	80-14
18	Svenska Sockerfabriks A/B, Landskrona	Sweden	Sugar	1919	3,900	7,700	35-11
19	Utansjö Cellulosafabriks A/B, Weda	,,	Pulp & Paper	1919	3,500	17,600	85-24
20	Stora Kopparbergs Bergslags A/B, Borlänge	,,	,,	1919	6,350	17,600	43-19
21	A/S Greaker Cellulosefabrik	Norway	,,	1919	6,200	30,000	100-30
22	A/B Henriksborgs Fabriker, Stockholm	Sweden	Oil Distillery	1919	1,250	4,400	114-33
23	S/A La Cellulose de Montech	France	Pulp & Paper	1920	8,850	28,500	107-35
24	A/S Toten Cellulosefabrik	Norway	,,	1920	6,200	32,600	114-14
25	Holmens Bruks & Fabriks A/B, Loddby, Norrköping	Sweden	,,	1920	3,500	13,000	100-28
26	A/B J. W. Enqvist O/Y, Tammerfors	Finland	,,	1920	3,900	17,600	85-11
27	A/S Saugbrugsforeningen	Norway	,,	1920	3,500	18,300	114-14
28	A/B Klippans Finpappersbruk	Sweden	,,	1920	2,800	7,700	39- 7
29	A/B Böksholms Sulfitfabrik	,,	,,	1920	2,500	7,200	85-28

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No.	Purchaser.	Country.	Industry.	Ordered	Accumulator. Volume.	Capacity.	Pressure.
					Cubic Feet.	Lbs. of Steam.	Lbs. per Sq. Inch.
30	Malmö Stads Gas and Elektricitetsverk	Sweden	Power Plant	1920	16,100	70,600	49–14
31	N. E. Nilssons Mejeri, Stockholm	,,	Dairy	1920	180	364	85–28
32	August Eklöf A/B, Borgå	Finland	Pulp & Paper	1920	3,200	15,400	87–88
33	Skönviks A/B, Ortviken, Sundsvall	Sweden	,,	1920	3,900	15,400	74–11
34	Krogstads Cellulosefabrik, Mjöndalen	Norway	,,	1920	6,200	22,050	100–28
35	A/B Papyrus, Mölndal	Sweden	,,	1920	3,000	12,100	114–28
36	Nyhamns Cellulosa A/B, Sundsvall	,,	,,	1920	4,400	16,500	121–35
37	A/S Embretsfos Fabrikker	Norway	,,	1920	6,000	29,800	114–14
38	A/S Katfos Fabrikker	,,	,,	1920	3,000	13,200	114–21
39	A/S Gulskogen Cellulosefabrik	,,	,,	1920	2,650	13,200	114–14
40	K. Tekniska Högskolan, Stockholm	Sweden	University	1920	700	5,700	170–14
41	A/B Mölnbacka-Trysil, Forshaga	,,	Pulp & Paper	1920	4,750	16,500	85–26
42	Sulfit A/B Göta	,,	,,	1920	3,350	13,200	114–28
43	O/Y Kajana Wood Ltd.	Finland	,,	1920	4,600	22,050	92–10
						18,800	92–18
44	Brown Corporation, La Tuque	Canada	,,	1920	3,200	17,900	125–15
45	A/B Korsnäs Cellulosafabriker, Karskär	Sweden	,,	1920	6,000	24,000	114–28
46	A/B Tegeforsverk, Järpen	,,	,,	1920	4,500	18,500	114–28
47	Ströms Bruks A/B	,,	,,	1921	2,800	8,500	107–28
48	A/B Stockholms Bryggerier, Hamburgerbryggeriet	,,	Brewery	1921	5,850	6,600	50–32
49	Malmö Yllefabriks A/B, Furulund	,,	Textile	1921	3,700	13,200	100–28
50	Strömsnäs Bruks A/B	,,	Pulp & Paper	1921	3,350	13,200	114–28
51	Schütze A/G, Zürich	Switzerland	Textile	1921	—	17,200	—
52	Herrn Altherr & Guex, Flawil	,,	,,	1921	3,500	11,000	142–57
53	Bultfabriks A/B, Hallstahammar	Sweden	Iron & Steel	1921	1,750	8,600	100–4
54	A/S Tuborgs Fabrikker, Copenhagen	Denmark	Brewery	1921	4,400	16,600	114–31
55	Tullis, Russell & Co., Ltd., Markinch	Scotland	Pulp & Paper	1921	3,500	14,000	115–30
56	Lessebo A/B	Sweden	,,	1921	4,250	13,200	85–28
57	Svenska Sockerfabriks A/B, Arlöf	,,	Sugar	1921	11,750	22,050	35–11
58	Bömich-Krumauer-Maschinenpapier Fabrik Ignaz Spiro & Sohn	Czecho-Slovakia	Pulp & Paper	1921	8,850	33,100	114–28

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No.	Purchaser.	Country.	Industry.	Accumulator. Ordered	Volume. Cubic Feet.	Capacity. Lbs. of Steam.	Pressure. Lbs. per Sq. Inch.
59	Sv. Jästfabriks A/B, Norra Jästfabriken, Rotebro	Sweden	Yeast Factory	1921	1,750	9,700	100- 7
60	O/Y Förenade Yllefabrikerna, Hälsingfors	Finland	Textile	1921	3,900	11,000	43- 7
61	A/B Walkiakoski	,,	Pulp & Paper	1921	6,000	23,200	94-21
62	Ängsösunds Mejeri, Enköping	Sweden	Dairy	1921	60	276	100-14
63	E. J. Höglanders Mejeri, Stockholm	,,	,,	1922	60	276	100-14
64	Oskarström Sulphite Mills A/B	,,	Pulp & Paper	1922	4,250	—	—
65	Eisenwerk, Lauchhammer	Germany	Iron & Steel	1922	24,800	66,200	28- 3
66	Yhtyneet Paperitehtaat, Jämsenkoski	Finland	Pulp & Paper	1922	8,850	35,300	100-21
67	Papier- & Zellstoffwerke A/G, Feldmühle, Stettin	Germany	,,	1922	10,600	37,500	114-35
68	Torps Mejeri, Bettna	Sweden	Dairy	1922	60	276	100-14
69	Halmstads Elektricitetsverk	,,	Power Plant	1922	2,800	15,100	142-28
70	Hjalmar Svenssons Mejeri, Göteborg	,,	Dairy	1922	71	287	100-14
71	"Cosmanos," Josefsthal	Czecho-Slovakia	Textile	1922	2,800	11,100	171-57
72	"Cosmanos," Lettowitz	,,	,,	1922	2,800	13,200	171-43
73	Solbackens Sanatorium, Kullsveden	Sweden	Hospital	1922	550	3,100	100- 7
74	Tuchfabrik G. Delius, Aachen	Germany	Textile	1922	5,300	9,900	100-57
75	Schlesische Leinenindustrie, Freiburg in Schlesien	,,	,,	1922	2,500	5,950	43-14
76	Meyer-Kaufmann Textilwerke A/G, Wüstegiersdorf	,,	,,	1922	5,400	14,350	57-14
77	Papierfabrik Baienfurt, C. Weingarten	,,	Pulp & Paper	1922	3,200	11,000	92-28
78	Textil-Ausrüstungs Ges. Krefeld-Haideck	Germany	Textile	1922	9,200	33,100	100-28
79	Köngsbergs Vaabenfabrik	Norway	Arsenal	1922	2,100	15,300	142- 7
80	A/S Hunsfos Fabrikker, Kristiansand	,,	Pulp & Paper	1922	4,250	26,500	142- 6
81	Deutsche Gold & Silberscheide-anstalt, Frankfurt a/M.	Germany	Chemical	1922	2,800	3,500	71-45
82	Boehringer A/G, Niederingelheim	,,	,,	1922	2,650	9,500	128-43
83	Djursholms Mejeri	Sweden	Dairy	1922	140	990	114-14
84	Hälsingborgs Gummifabriks A/B	,,	Rubber Factory	1922	2,800	8,800	171-71
85	Valio Mejeri, Hälsingfors	Finland	Dairy	1922	1,100	5,950	107- 7

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No.	Purchaser.	Country.	Industry.	Ordered	Accumulator. Volume. Cubic Feet.	Capacity. Lbs. of Steam.	Pressure. Lbs. per Sq. Inch.
86	Société Centrale des Bois, Paris	France	Saw-mill	1922	78	77	114-85
87	Kon. Papierfabrieken van Gelder Zonen, Velsen	Holland	Pulp & Paper	1922	11,300	43,000	114-28
88	A/B, J. A. Pripp & Son, Göteborg	Sweden	Brewery	1922	2,650	8,400	100-35
89	Koholyt A/G, Cosse b. Königsberg	Germany	Pulp & Paper	1922	12,400	33,100	100-43
90	Chem. Fabrik vormals Goldenberg, Winkel	,,	Chemical	1922	4,600	9,500	71-35
91	Vogel & Bernheimer A/G, Maxau	,,	Pulp & Paper	1922	9,550	24,900	85-35
92	Katrinefors A/B, Mariestad	Sweden	,,	1922	6,200	26,400	128-28
93	A. Ahlström O/Y, Warkausbruk	Finland	,,	1922	8,650	39,700	107-16
94	Hannoversche Maschinenbau A/G, Hannover-Linden	Germany	Power Plant	1923	23,400	100,600	142-28
95	Hannoversche Maschinenbau A/G, Hannover-Linden	,,	,,	1923	11,700	100,600	142-28
96	Kiener & Cie., Colmar	France	Textile	1922	11,300	39,700	114-35
97	Bahnkraftwerk, Altona	Germany	Power Plant	1922	10,600	44,100	213-71
98	Nederlandsche Stoomblekerij, Nijverdal	Holland	Bleachery	1922	3,500	8,800	142-71
99	Jubilee Exhibition, Göteborg	Sweden	Exhibition	1922	1,250	3,970	100-28
100	A. B. Iggesunds Bruk, Iggesund	,,	Pulp & Paper	1922	9,000	22,050	78-28
101	N. V. Vloerzeilfabrike Vogel v. Calcar, Zwolle	Holland	Textile	1922	2,100	9,050	142-35
102	Statens Järnvagar, Hagalund	Sweden	Railroad	1923	1,750	8,850	156-28
103	Raffinerie de Chantenay	France	Sugar	1922	5,850	17,600	57-11
104	J. Anderssons Mjölkförsäljning A/B, Göteborg	Sweden	Dairy	1923	60	330	114-14
105	Norrköpings Bomullsväveri A/B, Norrköping	,,	Textile	1923	1,600	5,950	114-28
106	International Paper Co., Piercefield	U.S.A.	Pulp & Paper	1923	6,070	29,000	100-15
107	International Paper Co., Niagara Falls	,,	,,	1923	6,070	35,000	130-15
108	Nederlandsche Kininefabriek, Maarsen	Holland	Chemical	1923	3,200	6,600	28-7
109	Tranås Vattenkuranstalt, Tranås	Sweden	Hospital	1923	530	1,750	85-21
110	Emil Mayen, Paris	France	Pulp & Paper	1923	3,500	11,000	100-35
111	Varziner Papierfabrik, Rathsdamnitz	Germany	,,	1923	6,200	22,050	85-28

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No.	Purchaser.	Country.	Industry.	Ordered	Accumulator. Volume. Cubic Feet.	Capacity. Lbs. of Steam.	Pressure. Lbs. per Sq. Inch.
112	A/G fur Bleicherei & Färberei, etc., Augsburg	Germany	Textile	1923	1,400	2,980	50–21
113	Deutsche Kaliwerke, A/G, Karlsfund	„	Chemical	1923	3,350	108	135–21
114	Kilsunds A/B, Borås	Sweden	Textile	1923	2,300	8,800	114–28
115	Paul Steinbock A/G, Frankfurt a/O	Germany	Pulp & Paper	1923	10,250	31,500	85–28
116	Kunstzandsteenfabriek "Arnoud," Hillegom	Holland	Chemical	1923	3,500	19,800	149–21
117	Gebr. Eberle, Forst in Lausitz	Germany	Textile	1923	71	3,850	142–21
118	Zellulosefabrik, Hinterberg-Leoben	Austria	Pulp & Paper	1923	7,100	25,800	114–35
119	Papierfabrik Steyrermühl	„	„	1923	4 750	19,600	114–28
120	Reymersholms Gamla Industri A/B, Karlshamn	Sweden	Chemical	1923	4,750	1,560	128–43
121	Hotel Continental, Stockholm	„	Hotel	1923	370	1,980	85– 7
122	Odense Sukkerkogeri, Odense	Denmark	Sugar	1923	2,800	8,150	85–35
123	Gebr. Aschaffenburg, München-Gladbach	Germany	Textile	1923	2,300	4,800	71–35
124	Bengtsfors Sulfit A/B, Bengtsfors	Sweden	Pulp & Paper	1923	6,700	19,800	85–21
125	Galizia Naphta A/G, Galizia	Poland	Chemical	1923	3,200	17,600	212–50
126	Sociètà Anonima Tintoria Crespi, Crespi sull'Adda	Italy	Textile	1923	4,100	11,000	114–50
127	Elektrizitätswerk, München	Germany	Power Plant	1923	6,200	—	200
128	Bergs A/B, Norrköping	Sweden	Textile	1923	1,750	—	—
129	Stamperia Italiana Ernesto de Angeli, Milano	Italy	„	1923	6,200	22,050	114–35
130	Svenska Sockerfabriks A/B, Göteborg	Sweden	Sugar	1923	11,700	26,500	57
131	Lemaire Destombes & Cie., Andrez lez Lille	France	Pulp & Paper	1923	3,500	11,000	85–28
132	A/B, Svensson & Hagberg, Borås	Sweden	Textile	1923	1,250	4,400	92–21
133	Koninklijke Stoomweverij te Nijverdal, Almelo	Holland	„	1923	3,900	16,500	85–16
134	Frydenlunds Bryggeri, Oslo	Norway	Brewery	1923	2,100	8,800	114–35
135	Bonneterie de Troyes	France	Textile	1923	7,100	22,050	135–47
136	Nydqvist & Holm, A/B, Trollhättan	Sweden	Iron & Steel	1924	4,400	22,050	114–14
137	Rydboholms A/B	„	Textile	1923	2,800	8,800	100–35
138	Meierei Bolle A/G, Berlin	Germany	Dairy	1923	2,400	7,150	38– 7
139	Motte & Co., Filature & Teinturerie, Mouscron	Belgium	Textile	1924	2,800	11,000	142–43
140	E. W. Justs Färgeri, Borås	Sweden	„	1924	1,250	5,500	170–35

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No.	Purchaser.	Country.	Industry.	Ordered	Accumulator. Volume.	Capacity.	Pressure.
					Cubic Feet.	Lbs. of Steam.	Lbs. per Sq. Inch.
141	Norrköpings Stads Nya Lasarett,	Sweden	Hospital	1924	900	—	—
142	Sacters Saapefabrik, Oslo	Norway	Soap Factory	1924	2,500	12,800	142-28
143	Kymmene Bruks A/B, Kuusankoski	Finland	Pulp & Paper	1924	10,400	49,500	100-14
144	Zellstofffabrik Aschaffenburg, Redenfelden	Germany	„	1924	3,900	13,300	85-28
145	M. B. Neumanns Söhne, Wien-Königinhof a/E.	Czecho-Slovakia	Textile	1924	2,300	5,100	114-64
146	Alpursa A/G Biessenhofen im Allgäu	Germany	Candy Factory	1924	3,000	13,000	171-50
147	Borås Wäfveri A/B, Borås	Sweden	Textile	1924	2,500	6,400	85-35
148	Zellstofffabrik Aschaffenburg, Stockstadt	Germany	Pulp & Paper	1924	3,840	13,300	85-28
149	Akers Kommunale Sykehus	Norway	Hospital	1924	2,650	16,500	142-14
150	Scheurer & Lauth, à Thann	France	Textile	1924	7,800	22,050	107
151	Zuckerfabrik Stöbnitz	Germany	Sugar	1924	4,600	15,400	85-28
152	A/B Eriksbergs Bryggeri, Göteborg	Sweden	Brewery	1924	1,240	4,900	114-28
153	Reichstabhndirection, Mittelsteine	Germany	Power Plant	1924	12,700	60,000	227-71
154	Chem. Fabr. vorm Weiler ter Meer, Uerdingen	„	Chemical	1924	9,200	23,000	71-28
155	Hamburger Hochbahn A/G, Hamburg	„	Power Plant	1924	11,700	48,500	213-71
156	Firma L. J. Wingqvist, Fritsla	Sweden	Textile	1924	3,500	8,600	71-28
157	Soc. An. Etabl. Moens Frères, Alost	Belgium	„	1924	2,800	8,600	85-28
158	Städt. Elektr' werk, Muffatwerk, München	Germany	Power Plant	1924	12,100	123,400	185-7
159	Lanificio di Gavardo, Brescia	Italy	Textile	1924	8,850	27,800	85-28
160	Sukkerraffinaderiet Phönix, Copenhagen	Denmark	Sugar	1924	3,500	15,400	128-28
161	Newfoundland Power & Paper Co., Ltd.,	Newfoundland	Pulp & Paper	1924	6,550	30,000	150-18
162	Alingsås Bomullsväveri A/B	Sweden	Textile	1924	1,400	3,300	82-34
163	Nääs Fabriks A/B, Floda Station	„	„	1924	530	1,980	156-43
164	Soc. Houillere de Sarre et Moselle, Carling	France	„	1924	1,400	7,700	71
165	Arp & Co., Nova-Friburgo, Rio de Janeiro	Brazil	„	—	—	—	—
166	Skandinaviska Gummi A/B, Viskafors	Sweden	Rubber Factory	1924	2,800	5,740	114-60
167	Manger Meieri, Bergen	Norway	Dairy	1924	350	2,200	142-7

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No.	Purchaser.	Country.	Industry.	Ordered	Accumulator. Volume. Cubic Feet.	Accumulator. Capacity. Lbs. of Steam.	Pressure. Lbs. per Sq. Inch.
168	Koppoms Pappersfabriks A/B, Åmotfors	Sweden	Pulp & Paper	1924	3,350	9,250	92-35
169	Utsiktens Bryggeri, Uddevalla	,,	Brewery	1924	565	2,200	100-21
170	Frankfurter Gasgesellschaft, Frankfurt a/M	Germany	Chemical	1924	2,200	1,550	43-28
171	Krähnholm Manufaktur, Narva	Esthonia	Textile	1924	810	3,300	142-43
172	Schlesische Zell. u. Paper. A/G, Cunnersdorf	Germany	Pulp & Paper	1924	2,200	8,150	85-21
173	Zellulosefabrik Villach, Seebach b/Villach	Austria	,,	1924	4,250	17,600	114-28
174	Hansa Bryggeri, Bergen	Norway	Brewery	1924	2,100	8,800	121-28
175	Gemeente Gasfabrieken van Amsterdam	Holland	Chemical	1924	530	410	14-7
176	Firma Kübler & Niethammer, Gröditz i/Sa.	Germany	Pulp & Paper	1924	6,100	2,200	171-43
177	Färberei Büschgens & Sohn, Krefeld	,,	Textile	1924	2,825	9,000	114-43
178	Schlesische Zell. u. Papier A/G, Maltsch	,,	Pulp & Paper	1924	5,300	16,500	100-35
179	Leonhardt Söhne, Crossen b. Zwickau	,,	,,	1925	5,300	12,600	114-57
180	A/B Fors Bruk, Östanfors Sulfitfabrik, Fors station	Sweden	,,	1925	4,400	13,200	100-35
181	Svanö A/B, Svanöbruk	,,	,,	1925	8,850	27,000	57-14
182	N. V. tot Exploitatie v. Ankersmit's Katoenfabr.	Holland	Textile	1925	2,825	11,000	171-50
183	Lanificio V. E. Marzotto, Valdagno	Italy	,,	1925	2,100	6,600	85-28
184	Färb. u. Appreturanstalt Georg Schieber A/G, Greiz	Germany	,,	1925	9,200	53,000	171-28
185	Deje. Sulfatfabrik Deje (A/B Mölnbacka-Trysil)	Sweden	Pulp & Paper	1925	2,800	7,300	142-71
186	Textilfabr. u. Färberei Scherzer & Honig, Forst N/L	Germany	Textile	1925	2,800	11,000	71-14
187	Lederfabr. Hirschberg, Hirschberg a/Saale	,,	Leather Factory	1925	4,250	28,600	171-7
188	Papierfabr. Gebr. Schiel, Busteni	Roumania	Pulp & Paper	1925	4,250	11,300	171-85
189	Tieleman & Dros, Leyden	Holland	Cannery	1925	2,300	9,900	142-35
190	Gebr. van Heek, Enschede	,,	Textile	1925	2,450	12,000	171-35
191	William Forrest & Son, Paisley	Scotland	Glue	1925	1,410	6,000	80-10
192	Jute Industries Ltd., Dundee	,,	Textile	1925	1,130	4,000	100-30
193	Price Bros. & Co., Ltd., Kenogami, Quebec	Canada	Pulp & Paper	1925	7,500	37,500	150-30
194	Mo & Domsjö A/B, Domsjö, near Örnsköldsvik	Sweden	,,	1925	13,100	48,500	114-32

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No.	Purchaser.	Country.	Industry.	Ordered	Accumulator. Volume. Cubic Feet.	Capacity. Lbs. of Steam.	Pressure. Lbs. per Sq. Inch.
195	Établissements Mauchauffée, Troyes	France	Textile	1925	4,250	13,200	171–71
196	Färb- u. Appreturanstalt George Schleber, Reichenbach	Germany	,,	1925	7,000	33,000	171–43
197	Städt. Elektrizitätswerk Muffatwerk, München	,,	Power Plant	1925	6,050	—	171
198	Zeche Lothringen, Dortmund	,,	Coal Mine	1925	4,250	4,150	142–14
199	Zellstoffabrik Waldhof, Tilsit i. Ostpr.	,,	Pulp & Paper	1925	8,470	25,300	92–35
200	Zellstoffabrik Waldhof, b. Mannheim	,,	,,	1925	9,830	26,700	170–85
201	St. Lawrence Paper Mills	Canada	,,	1925	4,000	24,000	150–20
202	Seedhill Finishing Co., Paisley	Scotland	Textile	1925	4,400	12,000	80–30
203	Textilfabr. Jenny & Schindler, Kennelbach	Austria	,,	1925	4,600	19,900	142–35
204	Nordische Papier & Zellstoffwerke, Reval	Esthonia	Pulp & Paper	1925	8,120	20,600	142–71
205	Hafslund Sulfitfabrik, Sarpsborg	Norway	,,	1925	4,250	17,200	100–21
206	Techn. Hochschule, Dresden	Germany	University	1925	2,820	15,400	114–14
207	Kammgarnspinnerei A/G, Leipzig	,,	Textile	1925	2,760	9,900	100–28
208	Färberei N. J. Monko, Enschede	Holland	,,	1925	1,100	3,850	171–64
209	Canada Sugar Refining Co.	Canada	Sugar	1925	10,000	40,000	90–15
210	Ste de Raffineries et Sucreries, St. Remi	France	,,	1925	5,300	16,500	142–57
211	Seifenfabr. F. Wolff & Sohn, Karlsruhe	Germany	Soap Factory	1925	1,950	8,700	171–43
212	Etabl. Rousseau, Paris	France	Textile	1925	160	—	100–70
213	Ste Calaisienne des pates à papier, Calais	,,	Pulp & Paper	1925	1,750	5,500	170–70
214	Reichsdruckerei, Berlin	Germany	Printing Office	1925	2,800	19,800	142– 7
215	Tuchfabrik F. F. Koswig, Finsterwalde N/L	,,	Textile	1925	2,800	13,200	123–21
216	Ulleval Kommunale Sygehus, Oslo	Norway	—	1925	3,530	24,000	142– 7
217	A/B, Skånska Yllefabriken, Kristianstad	Sweden	Textile	1925	2,120	6,600	142–57

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Summary.

	Volume, cubic feet.				Steam capacity, lbs.			
	Total.	Average.	Max.	Min.	Total.	Average.	Max.	Min.
Pulp and Paper Mills, 84 plants ordered - -	475,795	5,700	13,000	2,200	1,736,050	20,900	49,500	7,200
Textile Mills, 56 plants ordered - - -	177,885	3,280	11,300	160	669,200	12,230	53,000	1,400
Chemical Works, 20 plants ordered - -	64,920	3,310	7,200	530	184,660	9,260	28,600	410
Dairies, 10 plants ordered - - - -	4,485	448	2,000	60	16,025	1,602	7,200	330
Sugar Factories, 10 plants ordered - - -	65,700	6,300	11,700	2,800	203,700	15,400	40,000	7,700
Electric Power Stations, 10 plants ordered -	118,250	11,825	23,300	2,900	628,500	62,850	123,000	15,000
Iron Works and Mining, 5 plants ordered -	16,350	3,270	4,400	1,700	59,100	11,820	22,000	4,200
Breweries, 7 plants ordered - - - -	19,055	2,720	5,800	565	61,250	8,750	16,500	2,200
Public Establishments, 10 plants ordered -	14,280	1,085	2,820	530	77,100	5,240	16,500	1,800

Total, 212 plants ordered, with a total volume of 956,720 cubic feet, and a total steam capacity of 3,635,585.

Five additional plants are not included in this Summary.

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BIBLIOGRAPHY.

I. Books.

No.	Author.	Title.
1	Barth, F.	Wahl, Projektierung und Betrieb von Kraftanlagen, 3rd Edition, 1922, pp. 531-540.
2	Münzinger, F.	Die Leistungssteigerung von Grossdampfkesseln, 1922, pp. 139-144.
3	Rziha & Seidener	Starkstromtechnik, 5th Edition, 1921, p. 421.
4	Dubbel, H.	Taschenbuch für den Fabriksbetrieb, 1923, pp. 185-187.
5	Schneider, L.	Die Abwärmeverw. in Kraftmaschinenbetrieb, 1923, pp. 162-164.
6	Haack, J.	Beiträge zur Wärmewirtschaft. Druckschrift: Verlag Deutsche Bergwerkszeitung, Essen.
7	Hottinger, M.	Abwärmeverwertung, pp. 106-111.
8	Münzinger, F.	Amerikanische und deutsche Grossdampfkessel, Berlin, 1923, pp. 146-153, 162-165.
9	Wade, C. F.	A Manual of Fuel Economy, London, 1924, pp. 96-97.
10	Brouwer, G.	Zuiger - Stoomwerktuigen, Rotterdam, 1923, pp. 180-197.
11	Håkansson, H.	Undersökning på halvgasugnar, Ingeniörsvetenskapsakademiens Handlingar, No. 17, Stockholm, 1923, p. 76.
12	Stodola, A.	Dampf- u. Gasturbinen, Nachtrag zur 5ten Auflage, Berlin, 1924, Der Dampfspeicher von Ruths, pp. 15-21.
13	Allgemeine Elektricitäts-Gesellschaft	Wärmewirtschaft u. Zentralisierung der Kraftanlagen in den Zuckerfabriken, Berlin, 1922.
14	Allgemeine Elektricitäts-Gesellschaft	Kraft- u. Wärmewirtschaft in Papierindustrie, Berlin, 1924.
15	Troske, L.	Hütte, Taschenbuch des Betriebsingenieur, 1924, 24th Edition, pp. 442-444, 502-505.
16	Klingenberg, G.	Bau grosser Elektrizitetswerke, 2nd Edition, Berlin, 1924, pp. 50-57.
17	Münzinger, F.	Höchstdruckdampf, Berlin, 1924, pp. 119-122.
18	Enström, A.	Ingeniörsvetenskapsakadiens Handlingar, No. 37, Berättelse för åren 1919-1924, Stockholm, 1924, p. 31.
19	Dmitriew, V. V.	Parovlje Akkumulatorji, Leningrad, 1924, pp. 1-58.

Digitized by Google

No.	Author.	Title.
20	Ruths, J.	The Transactions of the First World Power Conference, II, "Steam Accumulation," pp. 1265-1288.
21	Münzinger, F.	The Transactions of the First World Power Conference, II, "High Pressure Boiler Plant," pp. 1349, 1359-62, 1365.
22	Rummel, K.	The Transactions of the First World Power Conference, II, "Blast Furnace Gas Economy," p. 1147.
23	Treitel	The Transactions of the First World Power Conference, II, "Exhaust Steam Engineering," p. 1161.
24	Rossander, C.	The Transactions of the First World Power Conference, III. "Low Tension Distribution and Electric Storage," p. 1098.
25	Lundberg, H. A.	The Transactions of the First World Power Conference, II., "Outstanding Features of Swedish Practice in Steam Power Production," pp. 1256-1258.
26	———	The Transactions of the First World Power Conference, II, "Steam Generation—Utilisation of Fuels"; Discussion (Enström, Klingenberg, Ruths), pp. 1321-1322.

II. Articles in Journals.

Swedish.

No.	Author.	Journal.	Title.
1	———	Svensk Papperstidning, 1919, No. 23, pp. 483-487.	Vaporackumulatorn.
2	Bäckström, M.	Teknisk Tidskrift (mekanik), 1920, No. 5, pp. 65-69.	Hållfasthetsberäkningar för uppläggningar av cylindriska, liggande behållare.
3	Frenne, N.	Industritidningen Norden, 1920, Nos. 27-28, pp. 217-221, 225-228.	Vaporackumulatorn, same article as in 4, T.T., 1920, No. 22.
4	Frenne, N.	Teknisk Tidskrift, 1920, No. 22 (Week Edition), pp. 261-270.	Vaporackumulatorn.
5	Olsson, G. O. M.	Svenska Vattenkraftföreningens Publ., 1920, No. 10 (124), p. 22.	Elektr. ångpannor.

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No.	Author.	Journal.	Title.
6	Olsson, G. O. M.	Svenska Bryggarefören, MÅnadsblad, 1921, No. 10, pp. 279-294.	Vaporackumulator-systemets tillämpning vid bryggerier.
7	Olsson, G. O. M.	Gas, Vatten & Värme, 1921, No. 1, p. 8.	Vaporackumulator-systemet.
8	Nordenson, T.	Uppsala Nya Tidning, 1922, No. 7994, p. 1.	Tekniska föreningens årssammanträde. On the accumulator.
9	Ulander, H.	Svenska Mejeritidningen, 1922, Nos. 3-4, 8 pp., 10 illustr.	Vaporackumulator-systemets användning vid mejerier.
10	Molin, H. M.	Svenska Elektr. verksföreningen, Handlingar år, 1922, Vol. 31, pp. 369-388, 7 illustr.	Reservkraftanläggning vid Malmö Elektricitetsverk.
11	Molin, H. M.	Teknisk Tidskrift, 1922, No. 48, pp. 763-768, illustr.	Reservkraftanläggning vid Malmö Elektricitetsverk.
12	Olsson, G. O. M.	Svenska Kemisk Tidskrift, 1922, No. 5, 11 pp., 6 illustr.	Vaporackumulatorn.
13	Sundblad, E. (S-d)	Svenska Papperstidn, 1922, No. 16, pp. 290-291.	Bort med tvånget i driften.
14	Ulander, H.	Handlingar till Lantbruksveckan, 1922, pp. 346-353.	Vaporackumulator-systemets användning vid mejerier.
15	Laurin, N.	Svenska Maskinisttidning, 1923, No. 1, pp. 10-12.	Vaporackumulatorn.
16	Laurin, N.	Eskilstuna Tekniska Skolas Förbunds Tidskrift, 1923, Nos. 2-3.	Vaporackumulatorn.
17	Karlsson, K. G.	Teknisk Tidskrift, 1923, No. 1, pp. 2-8.	3,750 kw. Laval-Turbinmaskiner för Malmö Stads Elektricitetsverk.
18	Josefsson, S.	Teknisk Tidskrift, 1923, No. 6, pp. 42-45.	Avprovning av nyutförd reservkraftanläggning vid Malmö Elektricitetsverk.
19	Sundblad, G.	Sv. Papperstidn, 1920, pp. 375-377.	Cellulosaindustriens bränsletillgång.
20	——	Norden, 1923, No. 28, p. 231.	Utställningen i Göteborg. On the accumulator.
21	Holm, Y.	Tekn. Tidskrift, 1924, Mek. No. 3, pp. 29-32.	Den nya reservanläggningen vid Halmstads Elektricitetsverk.

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No.	Author.	Journal.	Title.
22	Bäckström, M.	Tekn. Tidskrift, 1923, Mek. Nos. 6-7,	Turbiners förhållande vid variabel ångtillförsel, spec. strypreglerade.
23	Frödin, W.	Svenska Mejeritidningen, 1921, No. 48, pp. 368-369.	Mejeriers byggnad och montering.
24	Nordenson, T.	Borås Tidning, 30th April, 1923.	Ruths Ångackumulator och dess användning.
25	———	Från svenska Bruk, 1924, No. 5, p. 58.	Ruths-ackumulatorn.
26	———	Från svenska Bruk, 1924, No. 9, p. 114.	Japaner på studieresa i Sverige.
27	Berg, G.	Industritidningen Norden, 1924, No. 41, p. 325.	Brittiska Empireutställningen vid Wembley.
28	———	Gas, Vatten and Värme, 15th Jan., 1925, p. 4.	Användningar av ångackumulatorer.
29	———	Sv. Papperstidning, 1925, No. 10, p. 252.	Nya beställningar å Ruthsackumulatorer.
30	Håkansson, A.	Tekniska Föreningen i Finland Förh, 1920.	Om ångackumulering och vaporackumulatoranläggningar.
31	Nordenson, T.	Skandinavisk Tidskrift för Textilindustri 1923, pp. 55-60, 1924, pp. 172-177.	Dr. Ruths ångackumulator och dess användning speciellt inom textilindustrien.
32	———	Anglo - Swedish Trade Journal, 1924, p. 133.	Inslag av svensk ingeniörsverksamhet å Brittiska Empireutställningen.

German.

No.	Author.	Journal.	Title.
1	———	Elektrotechnik und Maschinenbau, 1920, p. 79.	Patentberichte aus dem Gebiete des Maschinenbaues.

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No.	Author.	Journal.	Title.
2	Billeb	Der Eisenbau, 1920, No. 18.	Angenähertes Trägheitsmoment und Widerstandsmoment für dünnwandige Rohre und verhältnissmässig grossem Durchmesser.
3	Josse, E.	Haupstelle für Wärmewirtschaft, 1921, p. 11.	Um- und Neubauten zur Verbesserung der Wärmeausnützung und ihre Wirtschaftlichkeit.
4	Håkansson, A.	Der Papierfabrikant, 1921, p. 16.	Ueber die Schwankungen im Dampfbedarf und die Anwendung des Vaporackumulatorsystems in der Zellstoff- und Papier-Industrie.
5	Uber & Hausbrand	Mitteilung des Berliner-Bezirksvereins deutscher Ingenieure, 1921, No. 12, pp. 167-170.	Wärmespeicher.
6	Kuhn, A.	Zellstoff u. Papier, 1921, No. 5, pp. 127-132.	Vorstandssitzung in Würzburg, 15th July, 1921.
7	Josse, E.	Gutachten, 1921.	Ueber das Dr. Ruthssche Dampfspeichersystem.
8	Josse, E.	Zeitschrift des Vereins deutscher Ingenieure, 1921, No. 45, p. 1170.	Jahresversammlung der Hauptstelle für Wärmewirtschaft.
9	Josse, E.	Archiv für Wärmewirtschaft, 1921, No. 11, p. 147.	Um- und Neubauten zur Verbesserung der Wärmeausnutzung und ihre Wirtschaft.
10	Barth, F.	Gesundheitsingenieur, 1921, No. 51, p. 640.	Kongress für Heizung und Lüftung.
11	Heilman	Zeitschrift für Dampfkessel- und Maschinenbetrieb, 1921, p. 319.	Wärmeausnutzung bei Kraftmaschinen.
12	Hldn (Halden)	Elektrotechnische Zeitschrift, 1921, No. 4, pp. 78-79.	Elektrische geheizte Dampfkessel in Schweden.

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No.	Author.	Journal.	Title.
13	———	Techn. Blätter zur Deutsch. Bergwerkszeitung, 1921, No. 44, p. 582.	Wärmeverwertungsanlage.
14	Dubbel, H.	Archiv für Wärmewirtschaft, 1922, No. 1, p. 1.	Der Ruths-Wärmespeicher.
15	Englert, F.	Mitt. techn. wissensch. V. Nürnberg, 1922, pp. 1-26.	Der Ruths-Wärmespeicher, sein Wesen und seine Bedeutung für die Dampfverbrauchenden Industrien.
16	Englert, F.	Die Wärme, 1922, Nos. 14-15, p. 170.	Der Ruths-Wärmespeicher sein Wesen und seine Bedeutung für die Dampfverbrauchenden Industrien.
17	Josse, E.	Zeitschrift des Vereins deutscher Ingenieure, 1922, No. 3, p. 62.	Kesselleistung und Wirkungsgrad bei schwankender Dampfentnahme.
18	Ohlmüller, F.	Siemens-Zeitschrift, 1922, No. 2, pp. 68-76.	Der Ruths-Dampfspeicher.
19	Rüster	Z. Bayer. Rev. V., 1922, No. 4, p. 30.	Der Ruths-Dampfspeicher.
20	Hausbrand & Ueber	Die Wärme, 1922, No. 3, p. 17.	Wärmespeicher.
21	de Grahl, G.	Z. f. angewandte Chemie, 1922, pp. 105-107.	Wärmewirtschaft bei "Spitzenleistungen."
22	Schulz	Stahl und Eisen, 1922, pp. 165-171.	Der Ruthsche Dampfspeicher.
23	Schmolke	Dinglers Polytechnisches Journal, 1922, No. 10, p. 104.	Der Rutsche Dampfspeicher.
24	Ruths, J.	Zeitschrift des Vereins deutscher Ingenieure, 1922, Nos. 21, 22, and 24, pp. 509-513, 537-542, 597-605.	Dampfspeicherung und Fabrikation.
25	———	Industrie und Handelsblatt d. Dortmunder Zeit. 62, Hauptversammlung des Vereins deutscher Ing., 1922, No. 281.	Report of a Paper by Dr. Ruths: "Dampfspeicherung und Fabrikation."

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No.	Author.	Journal.	Title.
26	Stein, Th.	Stahl und Eisen, 1922, No. 24, p. 925.	Der erste Ruths-Dampfspeicher in Deutschland.
27	De Grahl, G.	Glasers Annalen, 1922, pp. 123-126.	Nutzen der Wärmespeicher.
28	Schreber	Brennstoff- und Wärmewirtschaft, 1922.	Sparsame Temperaturwirtschaft.
29	Schreber	Dinglers Polytechnisches Journal, 1922, No. 7, pp. 61-65.	Sparsame Temperaturwirtschaft.
30	Krauss	Z. d. Dampfk. Unters. Ges., 1922, pp. 39-41, 48-51, 55-57, 69-71, etc.	Der Dampfspeicher von Dr. Ruths.
31	——	Stahl und Eisen, 1922, p. 1065.	Report of a Paper by Dr. Ruths: "Dampfspeicherung und Fabrikation."
32	Schulte	Techn. Mitt. und Nachr. d. Ver. Dortmund, 1922, pp. 94-95.	Ruths-Wärmespeicher.
33	——	Mitteilung des Berliner-Bezirks-vereins deutscher Ingenieure, 1922, No. 8, p. 85.	Festnummer der Zeitschrift des Vereines d. I.
34	——	Zeitschrift des Bayerischen Revisions Vereins, 1922, No. 13, p. 108.	Der Ruths-Dampfspeicher.
35	——	Gesundheitsingenieure, 1922, No. 28, p. 367.	Der Ruths-Dampfspeicher.
36	Wirth, F.	Die Wärme, 1922, No. 28, p. 347.	Die Wärmewirtschaft in der chemischen Industrie.
37	Klingenberg, G.	Elektrotechnik und Maschinenbau, 1922, No. 29, p. 344.	Die Zukunft der Energiewirtschaft Deutschlands.
38	——	Gesundheitsingenieur, 1922, No. 34, p. 443.	Patent: Die Momentanreserve von Ruths.
39	Müller, P.	Elektrische Kraftbetriebe und Bahnen, 1922, No. 8, pp. 193-196.	Der Ruths Dampfspeicher.
40	Boese, R.	Maschinenbau, 1922, pp. 504-511.	Die Speicherung von Wärme.
41	Münzinger, F.	Mitt. d. Verein d. El. Werke, 1922, No. 319, pp. 405-427.	Ruths Wärmespeicher in Kraftwerken.

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No.	Author.	Journal.	Title.
42	Lütte, P	Betriebsrätezeitung, 1922, No. 7, pp. 107-109.	Die Verwendung von Hochdruckdampf in Verbindung mit dem Ruths-Dampfspeicher.
43	Lütte, P.	Centralblatt der Hütten- und Walzwerke, 1922, No. 30, pp. 669-671.	Der Ruths Dampfspeicher.
44	Lütte, P.	Der technische Tag, 1922, No. 21.	Der Ruths Wärmespeicher. (Report from Z.d.V.d.I.)
45	Fichtl, Jos.	Gesundsheitsingenieur, 1922, No. 38, p. 490.	Der Ruths Dampfspeicher. (Report from Schweiz. Bauzeitung.)
46	———	Kali, 1922, No. 12, pp. 234-238.	Der Ruths-Dampfspeicher auf Grund der Patente der A. B. Vaporackumulator in Stockholm. (Survey of patents in Germany.)
47	Coerpe	Anzeigen für Berg. Hütten und Maschinenwesen, 1922, No. 109, pp. 108-111.	Der Wärmespeicher von Ruths.
48	Lüth	Technische Blätter der deutschen Bergwerkszeitung, 1922, No. 23, p. 233.	Die Verwendung von Hochdruckdampf in Verbindung mit dem Ruths-Dampfspeicher.
49	Glückauf	Glückauf, 1922, No. 27, p. 849.	Hauptversammlung des V.d.I.
50	Schreber	Die Wärme, 1922, pp. 353-354.	Von Honigmanns Natronlokomotive zum osmotischen Energiespeicher.
51	v. Le Juge	Die Wärme, 1922, No. 38, pp. 461-463.	Ruths-Wärmespeicher und Natron Wärmespeicher.
52	———	Elektrotechnik und Maschinenbau, 1922, No. 37, pp. 441-442.	Dampfspeicher, Bauart Ruths.
53	Kreyssig	Elektrotechnische Zeitschrift, 1922, No. 40, p. 1948.	Die Energiequellen Deutschlands und der Stand ihrer Ausnutzung.

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No.	Author.	Journal.	Title.
54	Gleichmann	Glückauf, 1922, No. 44, p. 1309.	Der Wärmespeicher von Ruths.
55	Lüth	Glückauf, 1922, No. 45, p. 1341.	Die Bedeutung des Ruths-Dampfspeichers für den Zechenbetrieb.
56	———	Gewerbefleiss, Vol. 101, No. 12, pp. 348-352.	Energieausgleich in Zechen und Hüttenbetrieben.
57	Quack, W.	Z. f. angewandte Chemie, 1922, No. 87, p. 623.	Probleme der Wärmewirtschaft in Deutschland.
58	Heyn, R.	Chemiker-Zeitung, 1922, No. 146, pp. 1105-1106.	Der Dampfspeicher von Ruths in der chemischen Industrie.
59	Kieselbach	Die Wärme, 1922, No. 50, p. 614.	Die Wärmespeicherung in der Dampfwirtschaft.
60	———	Centralblatt für Hütten- und Walzwerke, 1922, Nos. 49-52, pp. 1065-1067 and 1085-1087.	Energieausgleich in Zechen und Hüttenbetrieben.
61	Stein, T.	A. E. G. Mitteilungen, 1922, p. 239.	Energieausgleich in Zechen und Hüttenbetrieben.
62	Albohr	Melkerei-Zeitung, No. 81, 24th Oct. 1922.	Ein neuer Weg zur Kohlenersparnis.
63	Heyn, R.	Die Konserven-Industr., 5th Oct., 1922.	Der Dampfspeicher von Ruths und die Konservefabriken.
64	Englert, F.	Zellstoff- & Papier, 1922, pp. 213-223.	Der Ruths-Wärmespeicher, sein Wesen und seine Bedeutung für die Zellstoff- und Papierindustrie.
65	Englert, F.	Wochenblatt für Papierfabrikation, 19th Sept., 1922.	Der Ruths-Wärmespeicher in der Zellstoff- und Papierindustrie.
66	Klingenberg, G.	V.D.I., 1922, pp. 590-596,	Die Zukunft der Energiewirtschaft Deutschlands.
67	Krans, F.	Zeitschrift der Dampfkessel, untersuchungsverischerungsgesellschaft, 1922, Nos. 5-10.	Der Dampfspeicher Dr. Ruths.

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No.	Author.	Journal.	Title.
68	Classen, H.	Z. Dampfk. Vers. Ges., 1922, pp. 65-68.	Die Wärmewirtschaft der Zuckerfabriken.
69	zur Nedden	Mitteilung 39 der Wärmestelle Ver. d. Eisenhüttenleute, 1922, p. 31.	Ausnutzung von Abfallkraft und Abfallwärme elektrischer Kraftanlagen.
70	Gull, Constam	Schweizerischer Bauzeitung, 1922, No. 16, pp. 203-207.	Der Ruths-Dampfspeicher.
71	Möller, F.	Archiv f. Wärmewirtschaft, 1923, No. 1, pp. 3-6.	Die Wärmewirtschaft in der Textilindustrie unter Berücksichtigung der Abdampfverwertung.
72	Hottinger, M.	Gesundheitsingenieur, 1923, No. 3, pp. 30-32.	Verbindung von Dampfkraftund Heizanlagen und die Zwischendampfverwertung erzielbare Wärme- und Kohlenersparnis.
73	———	Feuerungstechnik XI., 1923, No. 8, pp. 89-90.	Dampfspeicher von Dr. Ing. Ruths (Report of articles in V.D.I. Zeitschrift, 1922, Nos. 21, 22, and 24).
74	———	Die Wärme, 1923, No. 5, p. 52.	Neueres über die spezifische Wärme und die Aufspeicherung des Wasserdampfes (Report of Dr. Ruth's article in Z.V.D.I., 1922).
75	Fischer, Alb.	Molkerei-Zeitung, Vol. 36, No. 88, pp. 1921-1923.	Der Rutssche Wärmespeicher in Molkereien.
76	Frenzel	Verbandsmitteilungen d. Dresdener Elektrotechnischen Vereins, Vol. 18, No. 2, pp. 5-9.	Wärmespeicher nach Dr. Ruths Vortrag, Dir. Kreyssig.
77	Thierbach, Dr. B.	Die Technik in der Landwirtschaft, Vol. 4, No. 4, pp. 69-72.	Die Bedeutung der Wärmespeicherung. in landwirtschaftlichen Nebenbetrieben.

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No.	Author.	Journal.	Title.
78	Treitel, H.	Die Naturwissenschaften, Vol. 11, No. 7, pp. 106-109.	Der Ruthsspeicher.
79	Stein, Th.	Das Deutsche Wollen-Gewerbe, No. 12, pp. 159-162.	Wärmewirtschaft und Ruthsspeicher im Textilbetrieb.
80	Molin, M. H.	Mitteilungen d. Vereinigung d. Elektrizitätswerke, Vol. 22, No. 330, pp. 46-53.	Die Reservekraftanlage im städtischen Elektrizitätswerk zu Malmö.
81	Pape, W.	Brennstoff- und Wärmewirtschaft, 1923, Bd. 5, Nos. 3-4, pp. 29-40, 48-56.	Kritische Betrachtungen über Anlagen mit Wärmespeichern.
82	Pape, W.	Der elektr. Betrieb, 1923, No. 2, p. 21.	Der osmotische Energiespeicher.
83	Heuser	Die Wärme, 1923, No. 22, p. 234.	Die Speicherung von Dampf zum Ausgleich von Feuerungs- und Verbrauchsschwankungen.
84	Pape, W.	Die Wärme, 1923, No. 25, p. 269.	Kritische Betrachtungen über Anlagen mit Wärmespeichern.
85	Lest	Wochenblatt für Papierfabrikation, 1923, No. 22, p. 1527.	Wärmespeicher.
86	———	V.D.I. Nachrichten, 1923, No. 15a.	Vortrag Dir. Kreyssigs im Mährischen Bezirksverein des VDI im 9. März, 1923, über Wärmespeicher nach Dr. Ruths.
87	Schiebl, K.	Centralblatt für die Zuckerindustrie, 1923, Nos. 40-42, pp. 812-815, 831-835, 852-855.	Neuzeitliche Mittel zur Verbesserung der Dampfwirtschaft in Rohzuckerfabriken.
88	Gerbel	Wochenschrift des Niederösterreichischen Gewerbevereins, 1923, pp. 63-65.	Behandlung wirtschaftlicher Probleme.
89	May, R.	Siemenszeitschrift, 1923, No. 6.	Bahnkraftwerke und Dampfspeicher.

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No.	Author.	Journal.	Title.
90	Hoepke	Feuerungstechnik, 1923, No. 19, p. 1923.	Der Dampfspeicher Dr. Ruths.
91	———	Die Wärme, 1923, No. 26, p. 285.	Dampfspeicher (Report from "Geschäftsbericht, 1922, des Würtemburgischen Revisionsvereins ".)
92	———	V.D.I. Nachrichten, Aug., 1923, No. 29, p. 1.	Der grösste bisher gebaute Ruths-Dampfspeicher.
93	Pauer	Die Wärme, 1923, No. 31, pp. 341-363.	Die Bedeutung verschiedener Speicherformen für die Energiewirtschaft.
94	Kreyssig, M.	Wochenblatt für Papierfabr, 1923, No. 47, pp. 2972-2976.	Der Ruthsspeicher in der Zellstoffabrik Lessebo A.G., Schweden.
95	Quack	Zeitschr. f. angewandte Chemie, No. 87, Jahrgäng, 35.	Probleme der Wärmewirtschaft in Deutschland.
96	Quack	Der Waggon- und Lokomotivbau, No. 12, Jahrgäng, 23.	Die Bedeutung der Dampfspeicher für Strassenbahn-Elektrizitätswerke.
97	Schiebl, K.	Centralblatt d. Zuckerindustrie, Nos. 40-42, Jahrgäng, 31.	Neuzeitige Mittel zur Verbesserung der Dampfwirtschaft in Rohzuckerfabriken.
98	Schiebl, K.	Mitt. d. Vereinig. d. Elektr. Werke, No. 338, Jahrgäng, 22.	Ruthsspeicher.
99	Schiebl, K.	Wochenblatt f. Papierfabrikation, 1923, No. 47, p. 2972-2976.	Der Ruthsspeicher in der Zellstoffabrik Lessebo A. G., Schweden.
100	Berner	Die Wärme, 1923, No. 29, pp. 315.	Bessere Ausnutzung der Braunkohle.
101	Hirsch	Die Wärme, 1923, No. 43, pp. 469-471.	Ueber das Zusammenwirken von Eigenkrafterzeugung und Fremdstrombezug bei gleichzeitigem Abwärmebedarf.

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No.	Author.	Journal.	Title.
102	Blau	Chemiker Zeitung, 1923, Nos. 101-102, pp. 709-710	Die Bedeutung des Ruthsspeichers für die neuzeitliche Kraft und Wärmewirtschaft.
103	Heyn, R.	Hamburger Technische Rundschau, 1923.	Die Betriebswirtschaftlichen Vorteile der Dampfspeicherung.
104	Rummel, K.	Mitteilung, Wärmestelle Düsseldorf, No. 57.	Formeln der Wirtschaftlichkeit von Dampfspeichern.
105	Rummel, K.	Archiv für Wärmewirtschaft, 1924, p. 144.	Formen und Wirtschaftlichkeit von Dampfspeichern. Ref. of K. Rummel.
106	Schmolke	Die Wärme, 1923, No. 46, p. 544.	Fortschritte in der Entwickelung der Wärmewirtschaft.
107	Schmolke	Feuerungstechnik, 1923-1924, p. 5.	Ruths-Wärmespeicher in Kraftwerken.
108	Schmolke	E.T.Z., 1923, p. 849.	Kritische Betrachtungen über Anlagen mit Wärmespeichern.
109	Josse, E.	V.D.I., 1924, No. 1, p. 12.	Chronik, 1923, Dampfkraftanlagen.
110	Fr.	V.D.I., 1924, p. 61.	Bahnkraftwerke und Dampfspeichern.
111	Zerkowitz, G.	V.D.I., 1924, No. 7, pp. 150-151.	Das Gegendruckverfahren und seine Anwendung bei der Dampfturbine.
112	Gesell	Wochenschrift für Brauerei, 1924, No. 16-2, p. 25.	Wärmespeicher in der Brauerei.
113	———	Die Wärme, 1924, No. 9, p. 109.	Wärmespeicherung im Kraftwerksbetrieb.
114	———	Feuerungstechnik, 1923-1924, No. 11, p. 92.	Kritische Betrachtungen über Anlagen mit Wärmespeichern.
115	Bientzle	Glasers Annalen, 1924, pp. 75-84.	Wärme und Betriebswirtschaftliche Vorteile des Ruthsspeichers.

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No.	Author.	Journal.	Title.
116	Grewin	V.D.I., 1924, No. 14, p. 346.	Die Entwicklung der Schwedischen Holzschliff-, Zellstoff-, und Papierindustrien.
117	Reichardt	V.D.I., 1924, No. 14, p. 348.	Schweden als Industrieland.
118	Lundberg, H. A.	Zeitschrift, V.D.I., 1924, No. 14, p. 342.	Schwedische Wärmewirtschaft.
119	Lundberg, H. A.	E.T.Z., 1924, No. 16, p. 374.	Energiespeicher in Zechen und Hüttenbetrieben.
120	Berner	Brennstoff Wärmewirtschaft, 1924, No. 2, pp. 21-28.	Neuer Aufgaben der Wärmetechnik.
121	Bientzle	Ann. Gew. Bauwesen, 1924, pp. 75-84.	Wärme- und betriebswirtschaftliche Vorteille des Ruthsspeichers.
122	Bientzle	Gesundheitsingenieur, 1924, p. 27.	Wärmespeicher in Verbindung mit Wasserkraft - Anlagen. (Ref. of F. Besser, "Zentralblatt der Bauverwaltung," Nos. 95-98, 1923.)
123	Bientzle	Die Wärme, 1924, No. 11, p. 111.	"Flachkompensator"
124	Schulze, R.	Die Wärme, 1914, No. 23, pp. 261-264.	Erste Verfahrungen und Versuche an einer Dr. Ruths Speicheranlage in Deutschland.
125	———	Die Wärme, 1924, No. 23, p. 269.	Wirtschaftlichkeit eines Braunkohlenkraftwerkes. (Ref. of Gleichmann Siemens Zeitschrift.)
126	Kieselbach	Die Wärme, 1924, No. 17, p. 175.	Der Gefällespeicher für Hoch- Mittel- und Niederdruck.
127	Teiweis	Die Wärme, 1924, p. 297.	Der Gefällespeicher für Hoch- Mittel- und Niederdruck.
128	Schieble, K.	Die Wärme, 1924, No. 27, p. 303.	Der Dampfverbrauch und dessen Schwankungen in Zuckerfabriken.

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No.	Author.	Journal.	Title.
129	Ohlmüller, F.	Die Wärme, 1924, No. 31,	Der Einfluss der neuern wärmetechnischen Entwicklung auf dem Kraftwerksbau.
130	Ohlmüller, F.	V.D.I., 1924, No. 34, p. 886.	Die Fortschritte der Dampftechnik in besondere durch den Hochdruckdampf.
131	Treitel, H.	V.D.I., 1924, No. 35, p. 901.	Gegenwärtiger Stand der Abdampftechnik und Abdampfwirtschaft in Deutschland.
132	Grunewald	Archiv für Wärmewirtschaft, 1924, No. 8, p. 145.	Die Wärmewirtschaft auf ersten rheinischen Braunkohlemesse.
133	Christians-Schulze, C.	Die Wärme, 1924, Heft 36, pp. 422-423.	Erste Erfahrungen und Versuche an einer Dr. Ruths Speicheranlage in Deutschland.
134	Berner	Die Wärme, 1924, No. 48, pp. 576-578.	Zuckerindustrie und neuere Wärmetechnik.
135	Berner	Feuerungstechnik, 1924-1925, Heft 1, p. 5.	Abdampfkompressions-aggregat und Dampfwidder.
136	Josse	Mitteilung der Ver. der Elektrizitätsw, 1924, Nos. 365-366, pp. 275-283, 297-304.	Die Fortschritte der Dampftechnik in besondere durch den Hochdruckdampf und Ihre Verwertung zur Verbilligung der Krafterzeugung.
137	Rummel, K.	V.D.I., 1924, p. 1143.	Die Hochofenwirtschaft und Eisenhüttenwerken.
138	Christ	Die Wärme, 1924. Nos. 46-47, pp. 548-550, 562-566.	Die Bedeutung des Ruths - Speicherns für Färbereien.

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No.	Author.	Journal.	Title.
139	Weber	V.D.I., 1924, No. 51, p. 1314.	Die Dampferzeugung auf der Welt-Kraftkonference.
140	Weber	Zeitschr. d. Bayrisch. Revisionsver, 1924, pp. 190-212.	Amtliche Verlautbarungen.
141	Herbst	Sparwirtschaft, 1924, Nos. 21-24, pp. 103-107.	Dampfspeicherung.
142	Rummel, Neumann	Mitteilungen d. Wärmestelle Düsseldorf, 1924, No. 66, p. 221.	Der Ausgleich in den Schwankungen zwischen der Gaserzeugung des Hochofen und dem Energiebedarf bei gemischten Eisenhüttenwerken.
143	———	A.E.G. Mitteilung, 1925, p. 13.	Wärmespeicherung in Kraftwerksbetrieb.
144	Pauer	V.D.I., 1925, No. 1, p. 21.	Chronik, 1924, Dampfkraftanlagen.
145	Kind	V.D.I., 1925, No. 2, pp. 44-46.	Wärmewirtschaft und Kraftversorgung in der Rübenzuckerindustrie.
146	———	Die Wärme, 1925, No. 6, p. 71.	Wärmetechnische Textiltagung der Mitteldeutschen Wärmestelle E.V. in Hanover.
147	Halle	Siemens Zeitschrift, 1925, No. 2, p. 77.	Der Ruthsspeicher in der Zuckerfabrik Stöbnitz.
148	Glinski	V.D.I., 1925, No. 6, p. 146.	Neuzeitliche Energiewirtschaft.
149	Gleichmann	Die Wärme. 1925, No. 9, p. 107.	Der Hochdruckdampf in der Braunkohlen-Brikettindustr.
150	Limprecht	Die Wärme, 1925, No. 12, p. 167.	Wirtschaftlichkeit der Verwendung von Hochdruckdampf für verschiedene Betriebsarten.
151	Freund	Zeitschrift des Österr. Ingenieur- und Architekten-Ver, 1925, Nos. 11-12, pp. 98-100.	Neuzeitliche Dampfdruck-Minderungs- und Regelventile.

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No.	Author.	Journal.	Title.
152	Aschof	Die Wärme, 1925, pp. 189-191.	Bericht über die Tagung der Wärmewirtschaftstelle westdeutscher Dampfkessel-Ueberwachungsvereine in Düsseldorf.
153	Eberle	Wochenblatt für Papierfabrikation, 1925, p. 389.	Einfluss des Hochdrucksdampfes auf die Dampfanlagen der Zellulose-industri.
154	Eberle	Die Wärme, 1925, No. 18, p. 235.	Einfluss des Hochdruckdampfes auf industrielle Dampfanlagen ins besondere auf solche in Textilindustri.
155	Schumacher	Die Wärme, 1925, Nos. 18-19, p. 240.	Die Beseitigung der Schwankungen in Dampfkessel und Dampfkraftanlagen
156	Philipp	Archiv für Wärmewirtschaft, 1925, No. 7, p. 187.	Dampfspeicherung und Produktionserhöhung.
157	Weber	V.D.I., 1925, No. 31, p. 1032.	Reinischer Dampfkesselbau.

English.

No.	Author.	Journal.	Title.
1	———	Chicago Commerce, 1920, p. 159.	Saving of Steam is Effected by New Swedish Invention.
2	———	Anglo-Swedish Trade Journal, 1920, No. 5, p. 135.	The Vaporaccumulator. A Remarkable Swedish Invention.
3	Schultz	Engineering, 1922, p. 240.	The Ruths System of Steam Storage.
4	———	Pottery Gazette and Glass Trade Review, 1922, No. 541, p. 1057.	The Ceramic Society in Scandinavia.
5	———	Practical Engineer, 1922, Vol. 65, pp. 1838-1843.	Ruths Accumulator.

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No.	Author.	Journal.	Title.
6	———	Swedish Export, 1922, No. 10, pp. 126-128.	The Ruths Steam Accumulator.
7	Englert, Dodge	Paper Trade Journal, 1922, No. 25, pp. 50-57,	The Ruths Heat Accumulator.
8	———	New Print Service Bureau	Steam Accumulators and Regenerators in Pulp and Paper Mills.
9	———	The Swedish-Australasian Trade Journal, Nov., 1922, p. 188.	The Ruths Steam Accumulator.
10	Enström, A.	The Baltic-Scandinavian Trade Review, Feb., 1923, p. 16.	Specialised Swedish Industries which have a Place in the World's Markets.
11	———	Power, 1923, No. 9, pp. 323-326.	The Steam Accumulator and its Applications.
12	Strohmeyer	Memorandum by Chief Engineer, 1922, pp. 24-32. The Manchester Steam Users' Association, 1923.	Thermal Storage.
13	Josse	Report on the Ruths Steam Accumulator.	
14	Townsend	Proceedings of the Ceramic Society, 1922-23, Vol. 22.	The Scandinavian Tour.
15	A. R. N.	Daily Bulletin of Gothenburg, 1923, No. 2, p. 29.	A Remarkable Swedish Invention.
16	———	The World's Paper Trade Review, 1924, p. 1496.	Discussion on Mr. Mallingson's Paper at Manchester. Mr. Nuttal mentioned Ruths Accumulator.
17	———	The Baltic Scandinavian Trade Review, 1924, No. 15, p. 41.	How to Store Surplus Steam for Later Use.
18	Ruths, J.	The First World Power Conference, Sweden, Paper No. 148, 15 pp.	Steam Accumulation.
19	Ruths, J.	Engineering, 1924, pp. 68-70.	Dr. Ruths' Paper read at the World Power Conference.
20	———	Chemistry and Industry, 1924, p. 721.	Dr. Ruths' Paper and Power Conference.

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No.	Author.	Journal.	Title.
21	— — —	Chemistry and Industry, 1924, pp. 764-765.	The Ruths Steam Accumulator.
22	———	Chemistry and Industry, 1924, p. 797.	Trade Information.
23	———	Engineering and Boiler House Review, 1924, Vol. 38, pp. 47-48.	Boiler House Exhibits at Wembley.
24	———	Anglo-Swedish Trade Journal, 1924, No. 7, 1925.	The World Power Conference.
25	———	Engineering and Boiler House Review, 1924, Vol. 38, p. 91.	The World Power Conference.
26	———	Power, 1924, Vol. 60, p. 164.	The First World Power Conference.
27	Brownlie	The Manchester Guardian Commercial, 28th Aug., 1924, p. 4.	The Efficiency of Steam Turbine.
28	Ruths, J.	The Machinery Market, 1924, Nos. 1245-1246. pp. 23-24.	Steam Accumulation.
29	— —	Paper, 1924, Vol. 34, pp. 662-664.	Workings of Ruths Steam Accumulator
30	— —	Iron and Coal Trades Review, 28th Aug., 1924.	Note Concerning Ruths' Accumulator for Newfoundland.
31	———	Anglo-Swedish Trade Journal, 1924, No. 9, pp. 261-265.	The Ruths Steam Accumulator.
32	Treitel, H.	Power, 1924, Vol. 60, p. 434.	German Practice in Exhaust Steam Engineering.
33	— — —	Power, 1924, Vol. 60, p. 550.	Storing Steam in Hot Water.
34	— —	Power, 1924, Vol. 60, p. 110.	Storing Energy.
35	— —	Beardmore News, Oct., 1924, p. 134.	Steam Accumulator for Newfoundland.
36	— —	The Empire Mail, Sept., 1924, p. 541.	Ruths Steam Accumulator Overseas.
37	———	The Rubber Age, Nov., 1924, pp. 485-488.	The Ruths Steam Accumulator.
38	— — —	The Engineer and Iron Trades Advertiser, 4th Nov., 1924.	Dr. Ruths.

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No.	Author.	Journal.	Title.
39	Taylor, A. J. T.	Power House, 5th Dec., 1924, pp. 31-34.	Steam Accumulators as a Factor in Power Costs.
40	Taylor, A. J. T.	The Canadian Engineer, 23rd Dec., 1924, pp. 631-633.	Ruths Accumulator for Steam Storage.
41	———	Paper, 23rd Dec., 1924, p. 420.	American Engineers and the Ruths Accumulator.
42	Münzinger	Combustion, Dec., 1924, pp. 430-435.	The Steam Accumulator.
43	———	Engineering, 19th Dec., 1924.	Personal and Business Announcement.
44	Taylor, A. J. T.	Pulp and Paper Magazine of Canada, 15th Jan., 1925.	The Ruths Steam Accumulator and its Applications.
45	———	The Machinery Market, 19th Dec., 1924, p. 17.	Power Stations and Politics.
46	Dawson	Engineering and Boiler House Review, Jan., 1925, pp. 279-281.	The Steam Accumulator.
47	———	Engineering and Boiler House Review, Jan., 1925, p. 297.	German Developments in Power Production.
48	———	Chemistry and Industry, Jan., 1925, p. 78.	Society of Chemical Industry (Paper by Hopkins).
49	Dawson	Engineering and Boiler House Review, Feb., 1925, p. 323.	How the Steam Accumulator Works.
50	Hopkins	Journal of the Society of Chemical Industry, 1925, Vol. 44, pp. 69-74.	Steam Accumulation.
51	Christie	Power, 1925, Vol. 61, p. 647.	Heat Accumulators.
52	Evans	Combustion, 1925, Vol. 12, pp. 416-422.	The Possibilities of Accumulators in a Large Modern Steam Plant.
53	Taylor, A. J. T.	The Paper Industry, 1925, Vol. 7, p. 390.	Developments in Steam Power Plants Equipment for the Modern Paper Mill.

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No.	Author.	Journal.	Title.
54	Taylor and Wettstein	Mechanical Engineering, 1925, Vol. 47, pp. 619-623.	The Ruths Steam Accumulator.
55	Löfgren	The Engineering Journal, Aug., 1925, pp. 352-355.	The Steam Accumulator.

Miscellaneous Foreign.

No.	Author.	Journal.	Title.
1	Andresen, S.	Elektroteknisk Tidskrift, 1919, No. 18, p. 71.	Dampktekniske Nyheder (Danish).
2	Constam-Gull	Le Génie Civil, 1921, pp. 454-457.	L'accumulateur de Vapeur Ruths (French).
3	Constam-Gull	L'Industria, 1921, pp. 521-527.	L'accumulatore di Vapore Ruths (Italian).
4	Håkanson, A.	Teknillinen Aikakauslehti, 1921, No. 3, pp. 261-271.	Vaporakkumulaatoreista (Finnish).
5	Håkanson, A.	Pappers-, Trävaru- och Industritidskrift.	(Finnish).
6	Hellemans	Rapport Vereenigung van Krachtwarktuigen, Sept., 1921, pp. 35-45.	Vaporackumulator (Dutch).
7	———	Le Génie Civil, 1922, No. 4, p. 95.	L'accumulateur de Vapeur Ruths.
8	———	Teknisk Ukeblad, 1921, pp. 27-32.	Vaporackumulatorsystemet (Norwegian).
9	Nolet	Polytechnisch Weekblad, 1922, No. 49-50.	De Stoomaccumulator System Dr. Ruths (Dutch).
10	———	Chambre de Commerce Française en Suède, 1923, No. 45, pp. 285-288.	L'accumulateur de vapeur Système Ruths.
11	Nordbeck	Tecnica Revista Tecnologico Industr., 1923, No. 60, pp. 191-192.	El Acumulador de Vapor Ruths (Spanish).

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No.	Author.	Journal.	Title.
12	———	Technitseskii Mir, 1924, No. 1, pp. 2-21.	Parovoi akkumuljator Rutsa (Russian).
13	———	Exportacion de Suecia. Oct., 1922, pp. 92-93.	El accumulador de Vapor Ruths (Spanish).
14	Drosne	Chaleur et Industrie, 1923, No. 8, pp. 713-723.	Les accumulateurs de vapeur (French).
15	———	Chambre de Commerce Française en Suède, 1923, No. 45, pp. 285-288.	L'accumulateur de vapeur Systeme Ruths (French).
16	———	Tidskrift för Papîrindustri, 1924, No. 1, p. 7.	A. B. Vaporackumulator Stockholm (Norwegian).
17	Hannover	Tekniska Forenings-Tidskrift, 48, 1924, No. 3.	Varmeakkumulatorer (Danish).
18	Thomson	Ingenioren, 1924, No. 12.	Tuborgs Fabrikkers nye Dampturbine og Dampfakkumulator anlaeg (Danish).
19	———	Denki Hyoron, 1925, 10 Maj, pp. 343-345.	(Japanese).
20	Marchand	Le monde industriel, Dec., 1924.	L'accumulation de la vapeur dans L'industrie textile (French).
21	———	Tidskrift for Industri, Dec., 1924, p. 231.	Dr. Ruths varmeakkumulator (Danish).
22	Medici	L'Industria, Dec., 1924, pp. 633-638.	Il calcolo termodinamico degli accumulatori di vapore (Italian).
23	Mariani	Ingegneria, 1924, No. 10, p. 371.	Le applicazioni degli accumulatori di vapore (Italian).
24	———	Le Nord Industriel, 10th Mar., 1923, pp. 434-436.	L'accumulateur de Vapeur Système Ruths (French).

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Discussion.

Mr. FRANK H. WHYSALL: I think Mr. Taylor tells his story in too general a way, a very common failing among authors of papers of this kind. What the prospective user most wants to know is not put in concrete form, and the recommendation amounts to an effort to induce the listener to make a trial at his own expense on the score that the apparatus is being adopted by others.

Mr. Taylor refers to the storage of electric energy in a lead accumulator, and in that form of storage there is, in most cases, the commercial difficulty of excessive cost. In specific cases it has proved satisfactory, but its application is limited. Energy has also been stored by pumping water, as at Walkerburn, not many miles from here, where water is pumped into a reservoir during the night, enabling mills which use the energy so stored to do away with any auxiliary form of power. In connection with the particular form of storing energy with which Mr. Taylor deals, he is quite right in assuming that our experience of it in this country is, to a large extent, limited; we generally associate it with collieries and exhaust steam turbines.

The application of an accumulator to a sugar refinery is particularly interesting to me, because I have been brought into very close contact with a problem of this kind. The electricity supply undertaking under my control made an arrangement with a local sugar house to install two triple-expansion engines and generators, to be used as reducing pressure sets, and it was estimated from information given by the management of the refinery that there would be enough steam to supply continuously 1,000 kw., and that 750 kw. of this total would be available for absorption in the town's mains, at a fuel cost less than could be obtained by the use of the most modern turbo-generating set. In practical operation there has always been the difficulty of an intermittent

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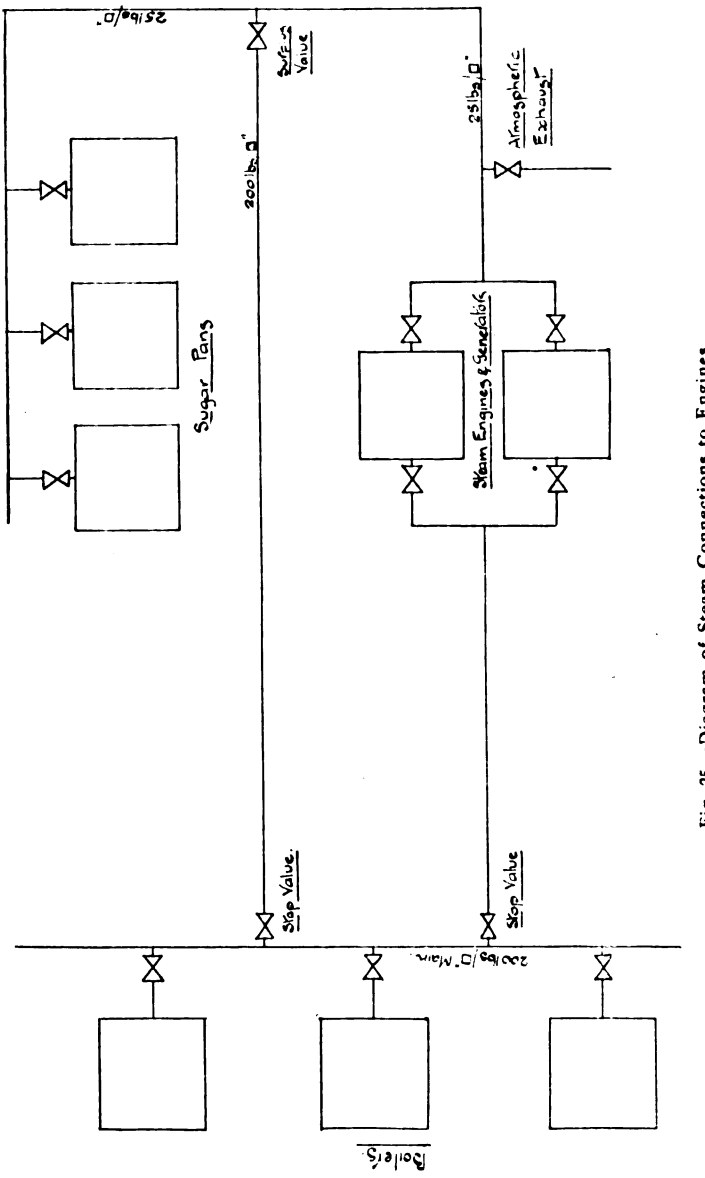

Fig. 25.—Diagram of Steam Connections to Engines.

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Mr. Frank H. Whysall.
demand for low-pressure steam, which causes the back pressure on the engines to rise to a figure necessitating reduction in the load. The quantity of exhaust steam at 25 lbs. pressure from these two sets working at full load is estimated to be 40,000 lbs. per hour, and I should be glad if Mr. Taylor would give the dimensions and cost of a Ruths steam accumulator installation capable of dealing with these conditions; a short outline of the conditions which prevail at the sugar refinery will no doubt suffice for a general estimate.

The steam is generated at 200 lbs. per square inch by a battery of boilers, and, as shown in Fig. 25, it passes through the two engines, and is exhausted into a 25 lbs. per square inch main. This pipe conveys it to the pans in the refinery. As before mentioned, the difficulty in connection with this is the constantly changing demand for steam by the pans, with the result that the power plant suffers.

Another point which occurs to me in connection with the Ruths steam accumulator is the number of automatic valves used. Even the best of these valves are often not so satisfactory in practice as in theory, and I should like to know what provision is adopted in cases of emergency.

I agree with Mr. Taylor that the general question of economics in engineering is daily becoming more important, and must be studied carefully if power for the world's work is to be supplied at a much lower cost.

Mr. Donald MacNicoll (Member): I have frequently observed the loss of energy from the safety valves of steam locomotives prior to their departure from termini stations and also when pulling up inclines, and some time ago I gave the matter careful consideration. I realised that this steam was additional to that used for carriage and feed heating, and I considered that steam storage was the only solution to the question of loss. The field for the storage of energy in locomotive work is, of course, limited, and on going into the

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Mr. Donald MacNicoll.

matter I was convinced that the first cost would outweigh any saving effected.

To my knowledge, overflow-pressure valves have been used for the last 25 or 30 years in this country in connection with high- and low-pressure boilers, and also in delivering surplus high-pressure steam from high-pressure boilers to low-pressure steam mains. In Fig. 6 I understand that OV is an overflow valve that allows the surplus steam above 150 lbs. pressure and below the pressure at which the boiler safety valves are set, say 155 lbs., to pass to the accumulator. As stated by Mr. Taylor, in the event of the boiler pressure not exceeding, say, 145 lbs. for some period, a reducing valve, RV, has to be provided when the accumulator has run down, to ensure a supply of reduced pressure at 25 lbs. Further, in the event of the steam which passes valve OV reaching 125 lbs. pressure (the limit for the accumulator), the valve MV closes, and prevents any further supply of high-pressure steam. Mr. Taylor says that the valve V_1 performs all these functions. To effect this I assume that, firstly, it is standing in a semi-open position, which gives a computed area sufficient to meet low-pressure demands of steam at 25 lbs., and secondly, that on the boiler pressure reaching, say, 151 lbs., it then opens further and passes steam until the 125 lbs. is reached, when it shuts off altogether. I should like Mr. Taylor to confirm this, or alternatively, to describe how the valve V_1, which I assume is that shown in Fig. 8, performs the three different functions when it is called upon to do so.

Mr. Kenneth Morrison (Associate Member): Mr. Taylor gives three steam consumption diagrams, the first, Fig. 11, having a minimum consumption of 28,000 lbs. and a maximum of 85,000 lbs., the mean consumption being about 45,000 lbs. per hour. This gives an increase above the mean output of about 89 per cent. Fig. 14 gives an increase above the mean output of about 58 per cent., and Fig. 17 about 50 per cent.

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Mr. Kenneth Morrison.

Perhaps Mr. Taylor will say if these figures are common, or if they represent isolated examples of bad conditions. A boiler of the Lancashire type is, owing to its large water space, particularly suited to varying load conditions, yet a boiler of this type, 30 feet long by 8 feet diameter, will release only about 450 lbs. of steam when the pressure falls from 120 to 100 lbs., assuming that the rate of firing remains constant. This quantity of steam only represents an increase over the normal evaporation for one hour of 6·6 per cent.

It would appear that there are fairly definite limits above the normal evaporations of different types of boilers when the installation of an accumulator would be commercially profitable. These limits would, of course, vary with the permissible pressure drop between the high- and low-pressure lines. If such figures are available, they would be of considerable interest to those engaged in the problem of economical steam supply.

Perhaps Mr. Taylor would amplify his remarks on the subject of superheated steam, since the use of superheaters, both as separate units and as integral parts of the boiler, is becoming more and more common. Is there any advantage in or objection to supplying superheated steam to the accumulator? Perhaps Mr. Taylor would also amplify his reference to the superheat accumulator, Fig. 16, for superheating the steam after leaving the accumulator. Is it possible to use a normal type of tubular superheater, either independently fired or heated by means of waste gases, for this purpose?

In conclusion, I would mention that the curves in Fig. 1, showing the amount of steam evaporated from a cubic foot of water, prove that the manufacturer who calls for low-pressure Lancashire boilers, or for a type which has a large water capacity, is not without reason for his choice, and the adoption of the accumulator would overcome many of the objections to using boilers of the more efficient water-tube type in processes where large and fluctuating volumes of steam are required at comparatively low pressures.

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Mr. George C. Usher.

Mr. GEORGE C. USHER: Published at a time when the conservation of coal and the development of cheap power are being widely discussed in relation to national and industrial economy, Mr. Taylor's paper dealing with the Ruths steam accumulator in its many industrial applications is of special interest, and will appeal to a wide circle of engineers and industrialists.

The storage of steam as an aid to economy has been given a great deal of consideration on the Continent, particularly in those countries where steam coal has to be imported. In this country, hitherto very little attention has been paid to the economics of steam utilisation in industry, but it is being increasingly recognised that the cost of manufactured articles may be very considerably affected by the cost of the steam used in the process of manufacture, and in future it will be necessary for the engineer to review every possible means of economy.

With hand- or stoker-fired boilers, it is difficult to meet the constantly varying steam demand which is characteristic of most industrial plants without sacrificing efficiency. To meet this difficulty the Ruths accumulator was introduced, the function of which, in its simplest application, is to enable the boilers to be operated at sensibly constant load. The accumulator is thus designed to overcome the disabilities of the hand- or stoker-fired boiler.

At the present time the pulverised-coal-fired boiler is rapidly gaining ground, and it is well to consider the possibilities of this system of firing in relation to the problem of steam generation under varying load conditions. In the most modern development of the pulverised-coal-fired boiler, a large percentage of the heating surface is located in the furnace, and absorbs heat by radiation, while the control of the fuel and air entering the furnace may be effected automatically. A change in steam demand is, therefore, met by an almost instantaneous alteration in the furnace temperature, and an equally rapid change in the rate of heat absorption by the

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Mr. George C. Usher.

boiler heating surface. In point of fact, the pulverised-coal-fired boiler is so flexible that, in the majority of installations, wide and rapid variations in steam demand can be met with an efficiency almost equal to that developed under constant load conditions. The extended use of pulverised-fuel equipment is, therefore, likely to solve many of the difficulties to overcome which the Ruths accumulator was developed.

As an adjunct to existing steam-raising equipment the Ruths accumulator has great possibilities, and the various applications discussed by Mr. Taylor admirably illustrate the wide variety of uses to which it may be put. In this respect, the application of the system as a stand-by for hydro-electric power plant is of outstanding interest.

From Fig. 1 it is obvious that the accumulator is most advantageously utilised where it is desired to store steam at relatively low pressure, and this fortunately is the condition met with in the majority of manufacturing processes where steam is required for heating or conditioning.

Mr. Taylor suggests the possibility of operating the accumulator in conjunction with the high-pressure boiler as a means of meeting variable load conditions, and mentions in this connection that with high-pressure boilers low water capacity cannot be counteracted by flexibility in the firing apparatus. While this is generally true of mechanical stokers which are incapable of rapid adjustment to meet varying steam demand, it is certainly not the case where the fuel is burned in pulverised form, for the reasons already discussed. Apart from this, an accumulator to operate at high pressure would require an almost prohibitive volume for any ordinary steam storage capacity, while the cost of construction would be heavy.

The above remarks are offered as a contribution to the discussion rather than as a criticism of any section of Mr. Taylor's valuable paper. The intention in submitting them is to indicate the merits of the pulverised-coal-fired boiler where

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load conditions are variable, and the noteworthy difference in this respect between pulverised-coal firing and stoker firing.

Mr. C. R. H. Bonn (Associate Member): I have been much impressed by the possibilities of the Ruths steam accumulator, more especially in connection with large electrical power stations. To those interested in this important development, some further explanation of various points would greatly increase the value of the paper.

The statement on page 19 concerning the capacity of the accumulator is not quite clear, and a little more information regarding the application of the diagram shown in Fig. 5 in connection with the steam-flow charts, in Figs. 11 and 12, would be useful. In Fig. 12 the accumulator pressure is shown as fluctuating with the pressure in the low-pressure boilers, but I presume that in an ordinary case the accumulator takes in steam at the higher pressure and gives it out at the lower. It seems quite obvious, therefore, that in the steam chart a number of larger areas above the mean line might be separated by insufficient areas below, to restore the accumulator. A supplementary diagram in connection with Figs. 7 and 8, showing in diagrammatic form the connections of B, the servo-motor, etc., would make the function of this all-important valve more easily understood; and a diagram showing the layout of an electrical power station, with accumulators for balancing the load, would be an important addition to the paper.

In a description of the Druitt-Halpin system,* data were given showing the very great advantage of steam storage over all other systems of power storage. The figures given for storage room per e.h.p. were from 4·06 to 6·4 cubic feet for steam storage, 20 cubic feet for illuminating gas storage, 80 cubic feet for fuel gas storage, and 317 cubic feet

* "Industries and Iron," 22nd March, 1895.

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Mr. C. R. H. Bonn.

at an elevation of 100 feet for water storage. If these figures are approximately correct, the enormous advantage of steam storage is proved.

I should like to know whether the installation shown in Fig. 18 differs in principle from the low-pressure turbine and Rateau regenerator combination installed in the rolling mill of the International Harvester Co., Chicago, and described in "Power" of June, 1907. The Druitt-Halpin system was designed to take steam at 265 lbs. and give it up at 130 lbs. As far as I can judge, the only real difference between the various systems of steam storage is in the method of control. It is just possible that automatic control may have retarded rather than encouraged the adaptation of the Ruths system in this country, where automatic devices are looked upon with suspicion, and where there is a decided preference for a man at the wheel.

I am pleased to see that Mr. Taylor has again emphasised the fact that inventions naturally develop faster in the country where they first receive commercial protection. The fact that so few imporant developments are receiving their first protection in this country nowadays is, I feel, one of the contributory causes of the depressed state of our industries. It is well known that the American and German patents are better and more saleable than British patents. Like everything else, inventions will find their way to the best market. It is true that many business directors have been imposed upon, but the indifferent treatment of inventors in this country drives them elsewhere. Vast sums of money, which might be employed in development at home, go out of the country annually in royalties for the questionable privilege of manufacturing some patented article or device, after the cream of the market has been skimmed off by the industry of the country in which the patent was first taken. I feel that we are indebted to Mr. Taylor for so strongly drawing attention to the question of prior protection,

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but unfortunately it is notoriously more difficult to correct an attitude of mind than to repair a deficiency in knowledge.

Mr. JAMES O. BAIRD (Member): This paper is of the greatest interest to those who use steam, not only for power but for process work, heating, or other purposes, and is of that high order which we associate with any contribution coming from Mr. Taylor. It detracts nothing from the praise due to Dr. Ruths for his work to acknowledge that previously done by Prof. Rateau and others on steam accumulators. It might be said that Rateau's work was for the cure of waste, that of Dr. Ruths for its prevention. While the usual heat absorbent medium in the Rateau accumulator is water, yet in its earlier forms pig-iron, steel rails, etc., were used, just as Dr. Ruths uses pig-iron for his regenerative superheater. A prominent Scottish engineer was so doubtful about the possibility of obtaining the amount of power claimed from exhaust steam with a Rateau accumulator that, before accepting the statement, he insisted on the live-steam pipe from the boilers being disconnected entirely. On this being done, it was amply demonstrated that a turbo-generator could attain full load on what had hitherto been waste heat.

In introducing any heat-saving device of this kind I can readily imagine that the greatest difficulty is experienced in securing reliable data of its performance. The number of steam measuring devices in use in this country must be infinitesimal compared with the number of steam plants. This, I am sure, is not the fault of the engineer or the works manager, but it is difficult to persuade the average board of directors that money spent on steam meters, or indeed any measurement device, will amply repay itself in a short time. It is not sufficient, as is amply shown by Mr. Taylor, to have a record of coal and water used per day or week; the consumption of steam for each process of manufacture from hour to hour, or even from minute to minute, should be known.

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Mr. James O. Baird.

Too little consideration is given to scientific control of makers' processes, and control instruments are frequently regarded as for laboratory rather than works use. Here is another channel of cheapening works costs that requires more attention. Granted that instruments for recording flow, volume, temperature, or pressure cannot in themselves affect economies, yet economies cannot be achieved without ample and complete records, which can be secured through the instrument makers of to-day. For this reason I welcome the remarks, on page 13, on the need of investigating existing conditions.

Mr. Taylor refers to Dr. Ruths' studies of the means of effecting efficiencies in the plants as a whole, and in my experience in large works I have been painfully struck by the fact that each departmental manager wants things to suit *his* particular corner and never considers the other departments, while even general managers or chief engineers are inclined sometimes to take too local a view of efficiency problems.

I do not altogether agree with Mr. Taylor in his remarks regarding the accumulator capacity of the Lancashire boiler as compared with the water-tube boiler. Where the steam from the boiler house is used entirely in the power house, it may be so, but on the other hand there is usually a fairly definite power curve from day to day which can easily be followed by forcing or slowing down the grates. Considering more especially the effects of the use of steam in process work, the power house will use steam at, say, 160 lbs. per square inch or higher, while the average pressure for process work will be probably of the nature of 40 lbs. or less. If, then, a sufficient number of boilers be allocated for the power house (any surplus of steam at low load passing by an overflow valve to the low-pressure main), while the remaining boilers supply the low-pressure main through a reducing valve, I think it will be found that there is a considerable thermal storage.

The control system appears to be ingeniously devised and carefully worked out to meet every contingency. One point,

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Mr. James O. Baird.

however, occurs to me, namely, that what is aimed at is constant temperature, yet the controls are based on pressure. Admitted that, generally speaking, pressure is a function of temperature, and also that the safety of the vessels necessitates the prevention of an undue pressure rise, it would seem more natural to put a temperature control on a thermal process. Control of temperature, as control of pressure, is best effected by a servo-motor of some kind, in fact in the former it becomes a necessity. One type of temperature control uses compressed air as the medium for operating the servo-motor. A capillary tube in the control instrument allows a small stream of air to pass through it, the nozzle of which is attached usually to the pen arm of a recording thermometer. On a similar arm, used for setting the control instrument to the required temperature, is a thin metallic disc. When the pen arm approaches this disc the nozzle is closed. This causes an increase of pressure in a diaphragm on the control head, which in turn operates a valve on the air line, opening or closing the valve according to the purpose to be served. The compressed air may be used to operate a steam valve, an electric switch, flue dampers, or other device for regulating the temperature.

While agreeing generally with Mr. Taylor's summary of the benefits of the accumulator system, I think he gives hardly enough acknowledgment of the work of the boiler-maker and instrument maker towards automatic boiler-house control. I should like to ask him whether there is so great a fluctuation of temperature in the boiler setting with fluctuating loads as he seems to indicate. With modern mechanical stokers the rate of feed of fuel can be varied through a wide range, and while the heat generated will consequently vary, it does not necessarily follow that the temperature does so to any extent.

Regarding the examples of applications of the principle, might I ask if the iron and steel works plant is an actual case or a hypothetical one? In Scotland, with coal-fired blast furnaces, the gas, even after treatment in the by-product plant,

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Mr. James O. Baird.

has proved a difficult proposition for the gas-engine maker, and, unfortunately, there is now only one combined blast-furnace and steel-works plant in Scotland. After much study it seems to me that the best proposition for such a plant in this country is to use gas under steam boilers, drive one mill—preferably the finishing mill, where the passes are long—by a steam engine, use the exhaust from this in an exhaust steam turbo-generator with accumulator, and drive the cogging mill and auxiliaries by electric motors.

I was particularly interested in Case 4, the stand-by for a hydro-electric plant, and an instance came to my mind where such an installation would have been useful even in a steam plant. I was called one night to a boiler-house breakdown which had put out of action the power station supplying, among other things, all the power for winding and ventilation in the pit. As the barometer was very low, the underground conditions were likely to become dangerous in a short time. Fortunately, through the willing help of the staff, the power station was set going again before any ill effects were felt underground.

Might I just briefly describe an attempt at the solution of a problem similar to some of the cases given in the paper, which at the time was the best I could devise, but which might be differently tackled in the light of Dr. Ruths' investigations and accomplishments? In a shale oil works, steam was used at 160 lbs. pressure in the power station, 40 lbs. in process work, and at atmospheric pressure in the retorts. Originally the load factor was such that the exhaust from the high-pressure engines was barely sufficient for the retorts. Gradually, however, the load factor increased beyond the retort requirements, and the surplus steam was used in vacuum evaporators. As it further increased it was found necessary to install turbo-generators designed to pass a fixed amount of steam at atmospheric pressure to those processes which could make use of such; excess over this was passed out at 40 lbs.

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to the low-pressure main, and any further requirements at that pressure were supplied through a reducing valve. This assured that no steam was wasted, incidentally solved other contingent problems, and proved quite a satisfactory solution.

Mr. W. W. MARRINER (Member of Council): Mr. Taylor refers to the accumulating effect of a large water content in boilers of the Lancashire type. The water-tube boiler is being increasingly used for land purposes, but for cotton and textile mills the Lancashire boiler is still preferred on account of its great capacity for heat storage. So it is obvious that, if an accumulator be fitted in conjunction with a water-tube boiler, all the advantages of a water-tube boiler, coupled with the heat storage of a Lancashire boiler, are obtained.

The Ruths accumulator is superior to the Lancashire boiler because there is no air passing through the accumulator or around it, and it is also very easy to lag compared with the Lancashire boiler. Makers of water-tube boilers welcome this accumulator, as a water-tube boiler is necessary for the economical burning of coal, especially when fitted with a mechanical grate which does away with the human element in the difficult operation of stoking a large boiler.

Mr. J. R. HAPPER: Mr. Taylor mentions that in July, 1924, there was only one installation of this kind in the British Empire. It so happens that I am identified with that installation, and, therefore, my position here may be unique in respect of having had experience of the actual operation of an accumulator.

There is no doubt always the tendency amongst engineers to adopt the policy of "wait and see," and it certainly requires initiative and the courage of one's convictions to launch out on a new venture not proved by others. As it happens, however, I am associated with a very progressive director of a factory who is always keen to adopt the best and most

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Mr. J. R. Hopper.

advanced ideas. After all, the steam accumulator is just the natural sequence of things. The wise man endeavours to accumulate a certain amount of savings for a rainy day. For years past the electrical engineer has used accumulators to meet the peak load. To go further back still, consider how water has been accumulated to meet the maximum demand, say, in large cities or in factories, and it, therefore, seems strange we have not advanced just so far in the case of steam storage between the source of generation and where it is consumed.

A previous speaker asks why a Lancashire boiler should not be used as an accumulator in series with a tubular boiler. There is not much to be gained in this way, for even although the Lancashire boiler may have the advantage of storage capacity, the tubular boiler makes up for this in the more rapid raising of steam, and they may, therefore, be placed on an equal footing. Apart from this, however, the accumulator requires special internal construction, and at the same time must be sturdily built, for, owing to the continual breathing action, due to the great range of constantly fluctuating pressure—in our case varying between 45 and 115 lbs.—it is subjected to rather severe strains. Generally speaking, a boiler, on the other hand, may only fluctuate a few pounds during working hours, and only once per week, perhaps when shutting down, may be called on to pass through a considerable range of pressure. Anyone with experience of the generation of steam in factory work knows that there are very often sudden and serious demands for steam which tend to upset all watchfulness on the part of firemen. Attempts have been made to meet this contingency by previous intimation to the firemen when the load was to be put on or off. This can only be looked on as a rough and ready means of overcoming the difficulty. The accumulator, however, automatically controls this trouble, and fills a much-felt want in regard to steadiness of demand on the boilers.

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Mr. J. R. Harper.

Where the accumulator is installed, it should be placed preferably near to its work, but although in the works with which I am connected there are about 1,200 feet of piping between the accumulator and the works, it acts quickly and steadily. The installation is linked up by a valve system to the turbo-generators, and, although doubt was expressed as to its effective working before installation, no trouble has been experienced, and confidence has grown.

I mentioned the necessity of having the accumulator strongly designed, and I refer to this again, because, as its efficiency depends very largely on its insulation covering, it will readily be seen that if a leakage occurs the covering must be removed and interfered with to effect a remedy.

Mr. Thomas A. Nordenson: There is particularly one point in the paper which I think ought to attract the interest of everyone who has anything to do with the working of steam-consuming apparatus as well as steam-generating plant, namely, that this accumulator system is not merely another steam- or fuel-saving apparatus amongst many others, but is really something more. It has been my fortune to inspect, at different times, a number of factories where these accumulator plants are working, and I may say that it is remarkable what a great improvement the accumulator has on the working conditions in these factories as a whole, and their boiler plants. As there is no longer any waiting for steam, it being available in sufficient quantity at any time and at the correct pressure, the process work is carried out at a quick rate and in a precise, standardised manner, without any anxiety or trouble. In the boiler-houses there also prevails a state of general peaceful steadiness and high efficiency in the operation.

In these days of severe competition, manufacturers should extract as much useful work out of their plant as possible. Although it is not always realised, it can often be proved, by careful investigation of the working conditions in factories, that

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Mr. Thomas A. Nordenson.
not the main manufacturing apparatus only but the boiler plant, or other auxiliary plant, is the "bottle-neck" of the production which restricts the output and makes it lower and more uneven in quality generally. With a full steam supply guaranteed by means of an accumulator, however, the output of a factory can be maintained at the highest, which is a very important matter in connection with overall economy in industry.

Accumulators are, therefore, an important means of obtaining the highest efficiency in steam-using industries, and the larger the units of the manufacturing apparatus are, the greater is the accumulator's utility from the standpoint of economic production, as delay in operation means greater total loss on a large unit than on a small one. In a Swedish factory where sulphite cellulose is made from wood in very large digesters, it was the custom, after a digester had been filled with wood chips, to sweep up those which fell on the floor and put them into the open digester before it was closed up and the process work started. A simple calculation showed that, by allowing the digesters to stand idle in this way for a few minutes while the chips were swept up and put back, there was a loss in the productivity of the digestory of from 5 to 10 shillings every time a digester was filled. This amount could have been, and was later on, saved by putting on the cover of the digester at once as the filling was finished, and using the chips on the floor for filling another digester. This shows how important it is, when large units are used, to let them run as continuously and at as quick a rate as possible.

Measuring instruments, particularly recorders for steam flow, boiler feed, CO_2 contents in flue gases, and steam pressure, are of great value for establishing a record of the actual operating conditions in industry, and to find out the means whereby they might be improved. The instruments used should be simple, well-protected, and rugged types that do not easily get out of order, even when they are not constantly

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looked after and their readings checked every day. The laboratory type of instrument is of no use for such purposes.

Not much is yet known concerning the possibilities of automatic boiler control, but everyday experience of boiler operation shows that it is difficult, if not impossible, to make the boilers follow a rapidly varying load, unless some form of storage is provided. If the fluctuations in the steam demand are large, great losses in fuel heat will necessarily follow, and the boilers, not well fitted for taking up variations in temperature, will be exposed to large local heat-stresses, thereby causing leakage and other troubles which shorten their life and increase the risk of operation.

Ruths accumulators, not being exposed to fire, and being of a simple, symmetrical form that can expand and contract freely under heat (which is evenly distributed in the shell), are eminently suitable for working at fluctuating pressures and temperatures.

Even through the best heat insulation there is a certain amount of heat loss, but on the accumulators there is a small ratio between the radiating surface and the volume of the shell. The actual heat losses are, therefore, not so large as might be imagined, and by using a first-class non-conducting material of sufficient thickness they can always be kept down to such a low value that they do not count in the balance sheet. As to the question of keeping heat units stored for some time, I might mention, as a rough figure, that if a Ruths accumulator of ordinary size is charged up to its full capacity, and all valves are closed to prevent any other heat loss than that through the insulating covering, it will lose, say, about one-half of the useful steam charge in about a week's time. This figure can be improved upon by thicker insulation, or by housing the accumulator to protect it from air circulation or wind, but it is seldom needed.

It is natural that the Ruths accumulator was first generally adopted in the industries of Scandinavia, where it was invented,

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and that from there it spread over the Continent; but, as mentioned by Mr. Happer, there is a plant in this country which has been working with great success for two years, and it might be of interest to members of the Institution to know that there are now being installed three more accumulator plants in Scotland, two at Paisley and one at Dundee, two of which will be in operation in the near future.

Mr. TAYLOR: I am indebted to Mr. Whysall for his opening remarks, in which he speaks of a common failing among authors of telling their story in a too general way. Without admitting the relevance of this criticism in my case, we all appreciate the general value of honest comment, and in the present instance I would like to point out why my paper was of necessity written on general lines.

In the first place, the subject of the Ruths accumulator cannot be comprehensively dealt with in anything short of six papers, and, therefore, feeling that it was time that this series of papers, in English, should be commenced, I have chosen my first paper to be merely an introduction to the subject. Introductions must of necessity be general if they hope to provide a foundation upon which a structure of broad and accurate knowledge can be erected. The purpose of the paper was made clear in the paragraph that set forth its four-fold object, but this paragraph did not appear in the rough proof of the paper which Mr. Whysall had the opportunity of reading; it is now included in the final edition.

Mr. Whysall refers to my paper as being, in part, an effort to induce the reader to make a trial at his own expense. Clearly my recommendation was to study the accumulator but not necessarily to try it, and surely the reference to existing plants is the best evidence one could give as to the merits of the accumulator. It is, in fact, a most striking thing that any invention could have every single one of its applications, from the earliest to the latest, spread before the world in a written

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detailed statement, without running the risk of causing either the owner of any of the individual pieces of apparatus or its inventor the slightest embarrassment. I doubt if there are many such instances of uniform success in the entire history of engineering.

The sugar refinery problem that Mr. Whysall presents is a typical case where process steam is used for generating power, the surplus power being supplied to the town's main. Difficulties have been encountered due to the fluctuating demand for process steam. The present layout of the plant is shown in Fig. 25. After remodelling the plant according to the Ruths accumulator system, the arrangement would be as shown by Fig. 26. A regulating valve V_1, of the overthrow type, would only pass as much steam to the engines as would maintain the boiler pressure constant at 200 lbs. This valve is also controlled by the low pressure, and if the demand for process steam is smaller than the supply of steam from the boilers, valve V_1 will start to close, and the surplus steam from the boilers will be passed through the overflow valve V_2 to the accumulator. If the demand for 25-lb. steam is larger than the supply through valve V_1, additional steam will be supplied from the accumulator through the reducing valve V_3. With this arrangement the boiler would have to generate steam according to the average demand, and an almost constant amount of power would be generated in the steam engines.

In order to fix the size of the accumulator, we require steam-flow diagrams of both the high- and low-pressure consumers that will give the fluctuations in steam demands throughout a 24-hour period. It is dangerous to generalise as to the probable size of a suitable accumulator, but I will hazard a guess that the accumulator will be between 4,000 and 6,000 cubic feet volume, and will cost completed from £4,500 to £7,000. I shall be glad to work this problem out in detail for Mr. Whysall if he will send me the additional data required.

As to the reliability of the regulating valves, it may be said

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that some of them have been in continuous operation for three years without giving any trouble at all. If something happens

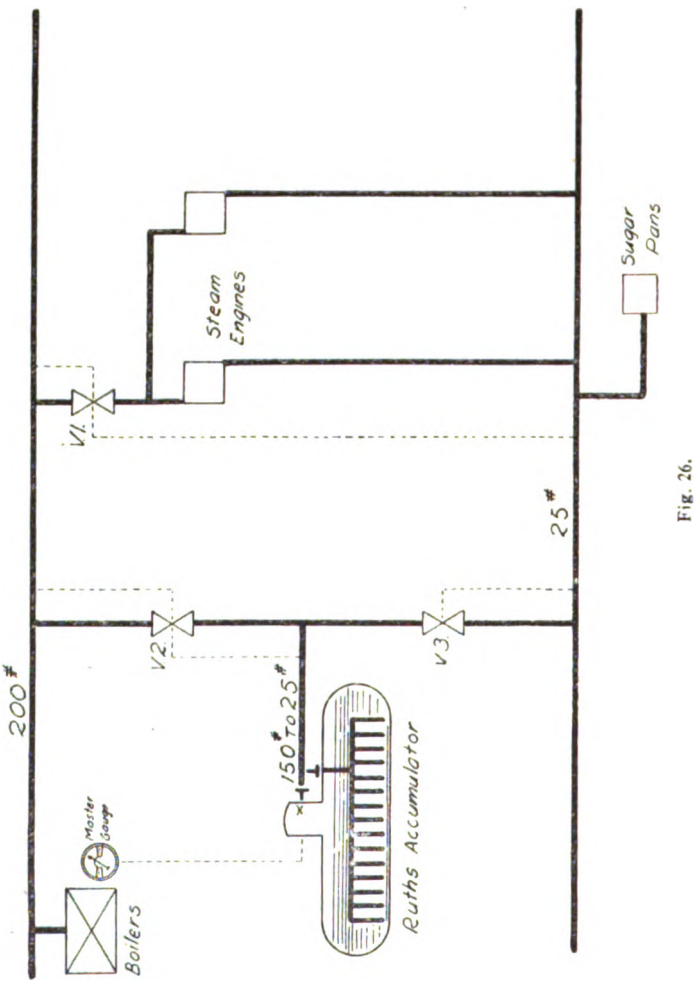

Fig. 26.

that disturbs the normal operation of the valve, the valve automatically closes. The valves are always equipped with

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a hand-wheel mounted on ball bearings, and can be quickly hand operated in case of emergency. They are the heart of the system, and are as reliable as any other piece of governing apparatus found in an industrial steam plant. Mr. MacNicoll asks for additional information as to the operation of the regulating valves for several impulses. Fig. 7 shows diagrammatically the arrangement of the pressure relay for one impulse. For two or three impulses, the relay is equipped with two diaphragms exposed to different pressures. The movement of these two diaphragms can be transmitted to the fork in the relay in such a way that any desired condition for opening and closing the valve can be obtained. Regulating valves have been built for four and five different impulses using two relays, each equipped with two diaphragms connected in series or parallel to each other. These regulating valves would require a complete paper for their full description. Their history is in itself extremely interesting, and their development has involved a long series of intricate experiments.

Mr. Morrison asks if the load curves shown in the paper are common, or if they are examples of bad conditions. A great number of curves of this type could be shown from different industries. Numerous tests made recently in a number of industries show that the majority have very fluctuating loads, but there is another point in this connection that is of still greater importance. In many plants the manufacturing processes have been arranged so that peaks in the steam demand are lessened. This often means that the manufacturing processes have been retarded, due to lack of steam, and so while an improvement has been made in the boiler-room conditions, it has been at the expense of either the quantity or quality of the production. With an accumulator the manufacturing plant can be conducted independently of the boiler-house, all peaks in the steam demand being taken care of by the accumulator. A good example of this is the

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steam consumption curves from a textile mill, with and without accumulator, shown in Fig. 11.

There is no objection to supplying superheated steam to the accumulator. It must be remembered that the steam discharged from the accumulator is always commercially dry. So if superheated steam is supplied to the accumulator, the heat content in each pound of steam supplied is greater than the heat content of each pound of steam discharged from the accumulator. The difference, however, is small, and is compensated for by the heat losses in the accumulator, due to radiation. As to superheating steam after it leaves the accumulator, any type of superheater may be used, separately fired or heated by waste gases, but the superheat accumulator shown in Fig. 16 is one designed actually to store the superheat already imparted to the steam before it reaches the accumulator proper, and to return this heat to the steam as it is discharged from the accumulator. Anything might be done with steam from the accumulator that can be done with steam of the same pressure direct from the boilers.

Mr. Morrison's closing remarks are of special interest, and manufacturers and users of steam boilers should squarely face the fact that we are rapidly approaching the time when the water content, and consequently the pressure parts, of the steam boiler of the future will be reduced to the minimum, and that the ideal boiler will be a simple coil of tube surrounding the source of heat. Increased pressures necessitate the reduction in size of the pressure parts, and the accumulator makes possible reduction in the water content of the boilers.

Mr. Usher's complimentary remarks are appreciated, and I am sorry that the necessity of the case requires that I should deal firmly with a most harmful and far-reaching fallacy that he has been betrayed into recording, namely, that flexibility of firing apparatus is a substitute in any sense of the word for steam storage.

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Mr. Usher is right in saying that pulverised fuel offers the greatest flexibility in coal-firing apparatus. It closely approaches the flexibility obtainable with oil or gas. Pulverised coal is really a gaseous fuel, but assuming that oil is being burnt instead of coal, thus obtaining the maximum of flexibility and the minimum of time lag in meeting steam demands, there are, nevertheless, two important limiting factors. First is the time lag, which is an appreciable thing, and ranges from 2 to 15 minutes, depending upon the size of the unit and the flexibility of the various pieces of control apparatus that have to be adjusted for the new load conditions. I refer to air-regulating ports, dampers, etc., none of which commence to function until there has been a definite drop in the steam pressure, as this is usually the actuating impulse. There is also in plants not fully equipped with automatic controls the inertia of the operator.

The next and more important limitation is the overload capacity of the boilers. Assume an average plant with the most modern installation of pulverised fuel, the latest type of water-tube boiler, and full automatic control. No one would expect the individual boiler unit to have an overload capacity greater than, say, 400 per cent. of normal rating, or the equivalent of an evaporation of from 12 to 15 lbs. of water per square foot of heating surface. If this be granted, then assume that the boiler plant is delivering at normal rating 50,000 lbs. of steam per hour. An instant demand is made. The best that pulverised coal or oil firing can do is to commence to supply steam at a rate of 200,000 lbs. per hour at the end, say, of the second minute in the demand, but the accumulator suffers from no such limitations. It can supply momentary demands of steam many times as great as the highest overload capacity of the boiler. In other words, the accumulator can discharge at the rate of, say, 600,000 lbs. per hour, without any greater time lag than that required for the passage of the steam from the accumulator through the

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valves and pipe. There can be no comparison between the flexibility of the discharge of steam from an accumulator and that of the generation of steam in a boiler. It is the difference between delivering instantly steam immediately available, and generating steam to fill a demand that usually cannot be anticipated.

All this argument leaves out of consideration another important factor, namely, that of efficiency. Rapid fluctuations, if met by any form of firing apparatus, always involve a certain loss in efficiency, and they further involve an increased cost of maintenance in furnace brickwork. It is a question whether the destructive effect of rapidly changing temperatures in a furnace has ever been fully appraised. By all means use pulverised fuel, the latest type of boiler, and the most effective form of air preheater, but let these several pieces of apparatus be run at the most efficient point, which is usually at a constant high rating, and at no time let it be thought that there is any conflict or competition between the functions of a steam accumulator and those of the other pieces of valuable apparatus just mentioned.

Mr. Usher remarks that an accumulator to operate at high pressure might be expensive. This is true, but in most industrial plants equipped with high-pressure boilers it is possible to locate the accumulator in the low-pressure range in such a way that not only is a maximum accumulating capacity for a given price obtained, but an accumulator constructed for a low initial pressure may be used.

In the examples given in the paper, it will be noticed that the accumulator in every instance is located in the low-pressure range. To give another example, take a central station in which the high-pressure turbines receive steam at, say, 1,200 lbs., exhausting at, say, 150 lbs. to the low-pressure turbines. The accumulator would be installed either between the high- and low-pressure turbines, in which case it would have to be built to withstand 150 lbs., or it would be installed

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between the intermediate- and the low-pressure stages of the low-pressure turbine, where it might only require to be built for a maximum pressure of 75 lbs. This is not an actual practical example, but it illustrates the principle that it is seldom necessary to design the accumulator to withstand the boiler pressure. A valuable contribution on the subject of the relationship between high-pressure boilers and the accumulator is given in Dr. Frederick Münzinger's World Power Conference paper, referred to in the Bibliography accompanying my paper, item 21, page 63.

Mr. Bonn wishes further explanation as to my reference to the capacity of accumulators. The capacity of the accumulator can be determined in about the same way as the water storage reservoirs for hydro-electric stations, *i.e.*, by comparing demand and supply over a long period, say, for instance, 24 hours.

The diagram shown in Fig. 5 will be better understood when compared with the description of the regulating switchboard on page 23, as shown in Fig. 2. A supplementary description of the regulating valves will be given in my forthcoming paper on these valves, and at the same time the application of the Ruths accumulator regulating system to turbines in industrial and electrical power plants will be discussed in detail, so I ask to be excused from dealing more fully with the matter now.

In Fig. 12, the accumulator pressure is shown as fluctuating with the pressure in the low-pressure boilers. It is true, as Mr. Bonn remarks, that in ordinary cases the accumulator pressure alone fluctuates, the boiler pressure being maintained constant. In the case just referred to, however, the old low-pressure boilers were used as accumulators, thus making an addition to the accumulating capacity of the system as a whole.

In reference to Mr. Bonn's question as to the arrangement of an electrical power station with accumulators for balancing the load, I may say that this would be about the same as that

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shown in Fig. 18, *i.e.*, the accumulator would be discharged into the first or second stage of a condensing turbine equipped with two sets of nozzles, one for live steam and one for accumulator steam.

In addition to the figures quoted by Mr. Bonn for storage space required per e.h.p. from the description of the Druitt-Halpin system, the following figures may be of interest:—

Kind of Storage.	Relative energy stored per pound of substance.
Fly-wheel travelling a mile per minute - -	1
Hot water (100 lbs. gauge to 50 lbs.) - -	334
Dynamite - - - - - - - -	7,500
Coal - - - - - - - - -	83,500
Oil - - - - - - - - -	125,000
Hydrogen - - - - - - - -	400,000

There is no resemblance at all between the arrangement shown in Fig. 18 and the arrangement described in the article in "Power" of June, 1907, showing a low-pressure turbine and a Rateau regenerator installed in a rolling mill of the International Harvester Co., Chicago. The Rateau regenerator receives all the steam coming from steam engines at an intermittent rate, and delivers this steam at a fairly constant rate to a low-pressure turbine, whereas the Ruths accumulator, Fig. 18, is connected in parallel with the turbine, and only receives such a quantity of steam as is required to cover the peak loads, and, further, the regulation of the two accumulators is entirely different.

The automatic control features do not retard the introduction of the accumulator. British engineers freely accept the most sensitive automatic devices, as, for instance, the many forms of speed governors. Complete ignorance of the accumulator functions and its practical importance is responsible for its late introduction to the English-speaking world.

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Mr. Marriner is entirely right in the assumption that the Ruths accumulator will very much increase the usefulness and flexibility of the present water-tube boiler, and will overcome entirely the handicap which that type of boiler has under fluctuating loads when compared with boilers of the Lancashire type. Mr. Marriner is also correct in drawing attention to the fact that the storage capacity of the Ruths accumulator is not only much greater than the capacity of a Lancashire boiler, but it is much better insulated and less expensive to maintain.

I have already made reference to the tendency to decrease the water content of boilers for high pressure, and to substitute an accumulator, the water content of which may be made common to a battery of water-tube boilers. The nearer water-tube boiler design approaches a plain tube of small diameter, the cheaper the boiler construction will be as the pressure increases.

I am particularly obliged to Mr. Happer for his contribution to the discussion. It is always a pleasure to hear directly from a pioneer, and to know that the introduction of the first accumulator in the English-speaking world not only took place in Scotland, but has proved to be entirely satisfactory to those who had the courage to undertake its application. Mr. Happer's point in regard to the necessity of removing the insulating covering when a leak develops in the accumulator tank refers to a difficulty that may easily be avoided if sufficient care is exercised in the manufacture of the tank in the first place, and providing the accumulator is not unduly strained during its tests. There are many accumulators which have been in operation for long periods without having any part of the insulation removed, and it is quite possible that improvements will be made in the design of the insulating covering to permit its easy removal at points over the girth seams, so that these may be inspected periodically.

Mr. Nordenson speaks from a long and intimate experience

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with the accumulator, and I am pleased to see that he has drawn attention to the very low heat-loss from the accumulator itself. This rarely exceeds one-half per cent. of the coal used to generate the steam stored in the accumulator. The ratio of the area of the exposed surface to the heat content of the accumulator is so low for practical purposes that loss of heat through radiation is negligible.

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THE JUBILEE OF THE MARINE SPRING-LOADED SAFETY VALVE.

By Donald MacNicoll,
Member of the Institution.

20th October, 1925

In the year 1875 the British Board of Trade finally gave way to the incessant demand of marine engineers that spring-loaded safety valves should be fitted to the boilers of steamships in place of deadweight safety valves, either directly loaded or through the medium of a lever. Foremost amongst marine engineers in this connection were those of the Clyde district.

Sporadic efforts had been made to induce the Board to approve, or at least not to object to, the use of spring-loaded safety valves for marine purposes, but it was not until engineers were banded together under the influence of this Institution that the Board of Trade could be effectively dealt with. Now the position in the early seventies of last century was this, that every locomotive in the country—and there were not a few—was fitted with spring-loaded valves, and every steamship, of which there were a considerable number, was fitted with deadweight valves. Why? To solve this it is necessary to turn over the pages of history.

The safety valve was invented by a Frenchman, Dr. Denys Papin, who was contemporary with the Marquess of Worcester and Savery in England, and who used it in conjunction with his digester towards the end of the seventeenth century. The digester with its deadweight valve is shown in Fig. 1. According to Hebert's Encyclopædia, Papin also produced an

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engine in 1707. No particular claim is made for this engine, but, incidentally, the illustration in the encyclopædia shows a safety valve; the engine with its safety valve is illustrated in

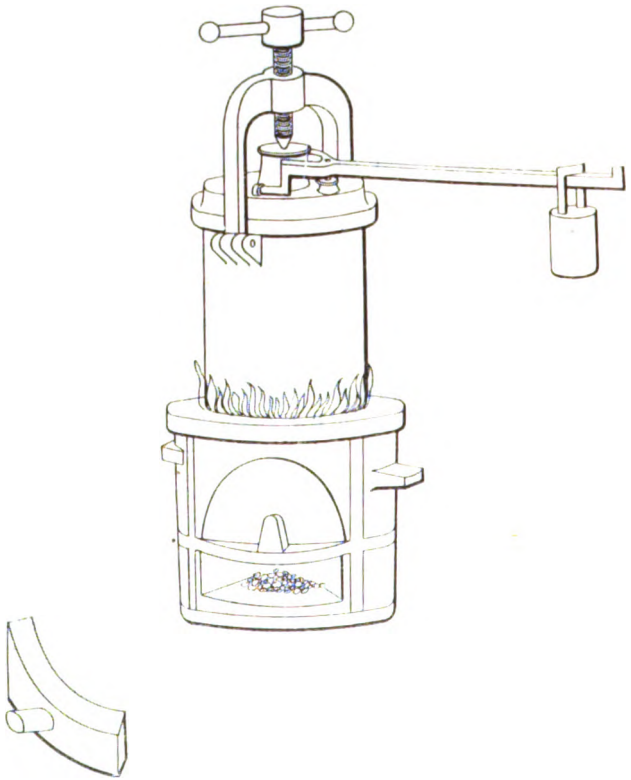

Fig. 1.

Fig. 2. On these grounds we are compelled to acknowledge that the safety valve originated in France.

Obviously the simplest form of safety valve is one loaded with a deadweight, and of deadweight types the simplest form is one having a direct deadweight. Again, of direct deadweight valves the simplest form is a weight in the nature of

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a ball covering an orifice. A valve of this type was invented by Mr. Benjamin Hicks, of Bolton, and is shown in Fig. 3.

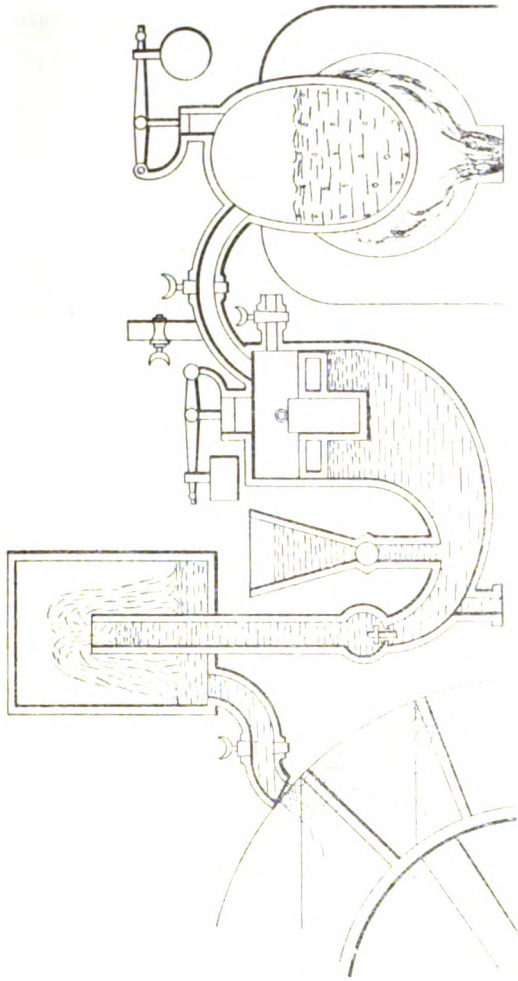

Fig. 2.

The first steam boilers were all stationary, so that there was no need for any type of safety valve other than the deadweight.

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Practical steam navigation came a little earlier than steam locomotion on land, and the first practical steamboat in this country was the "Comet," while its contemporary in the New World was the "Clermont." In both these cases navigation was what might be termed inland. Consequently the motion of the vessels was slight—at least there was little

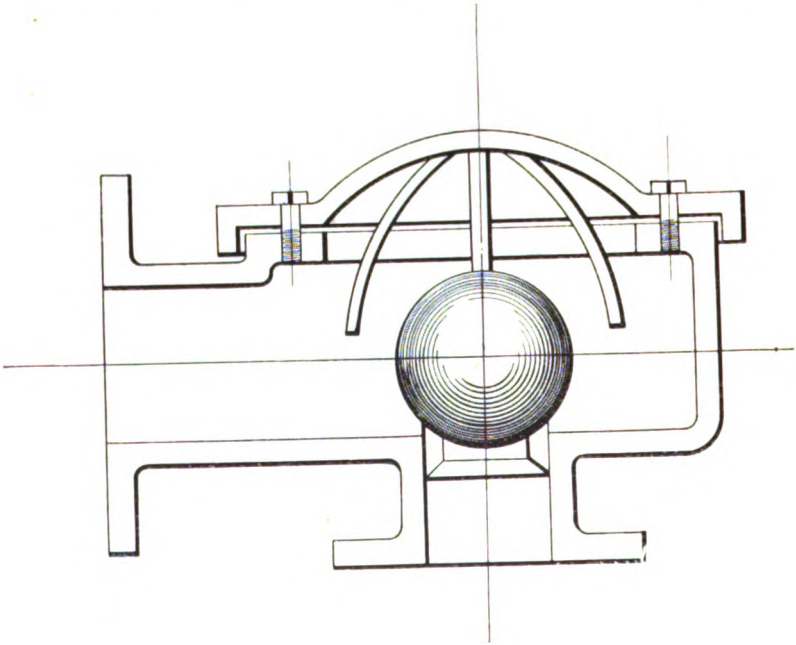

Fig. 3.

likelihood of their being otherwise than on an even keel—so that a deadweight safety valve for the boilers appeared to be only natural. This created a precedent, and a precedent is a great thing in engineering.

George Stephenson constructed locomotives about 1812, and in 1817 he built a locomotive which was run on the Duke of Portland's Railway between Kilmarnock and Troon. But the first practical railroad to carry passengers and to be worked

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by steam locomotives was the Stockton and Darlington Railway. I believe most of those early locomotives had spring-loaded safety valves. It is hardly necessary to point out how very unsuitable a deadweight valve would be if fitted to the boiler of a steam carriage or locomotive when travelling at over 20 miles an hour, on account of oscillation and vibration. Obviously a spring-loaded valve was the most suitable fitting. With the continued development of marine propulsion, engineers began to experience difficulties with the deadweight valve on the boilers then in use, and in 1870 the position became acute, for steam pressures had been steadily increasing, and had reached 100 lbs per square inch.

In the beginning of that year John Elder made the compound engine for marine purposes a commercial success, and engineers realised two important facts. Firstly, that the Board of Trade rule which gave half-a-square-inch of valve area per square foot of grate surface for all pressures was wrong; and secondly, that when the ship rolled the loss of steam through the deadweight valves lifting was much greater at the higher pressures. The extent of this loss will be fully understood, particularly when for an absolute pressure of 100 lbs. the area of safety valve by regulation was the same as for a pressure of 10 lbs., whereas it should have been inversely proportional to the pressures. Thus to discharge the same weight of steam the area of a valve for 100 lbs. need only be $\frac{1}{10}$th of the area for 10 lbs.

In April, 1872, Mr. James Howden read a paper before this Institution on "A Rule for Determining the Areas of the Safety Valves of Steam Boilers in Relation to their Power and Pressure," wherein he advocated the fitting of two safety valves, one loaded by deadweight and the other by a spring. Other papers followed, the most outstanding of which was that by Mr. Hazelton Robson, who was peculiarly fitted to deal with the subject of safety valves in their relationship to the Board of Trade, as he had previously been a Board of

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Trade surveyor of some note. He was an outstanding figure of his time, and his views on engineering matters were listened to with such respect that I think it might not be out of place to quote from his obituary notice as it appeared in Vol. L of the Institution's Transactions:—

Hazelton Robson was born in South Shields on 12th April, 1823, and received his early training and experience in engineering in the well-known works of Messrs. Hawthorn, Newcastle-on-Tyne (now R. & W. Hawthorn, Leslie & Co., Ltd.). At the early age of 24 he accepted a position of trust in the extension of Messrs. Hawthorn's works at Leith, and in this capacity he superintended several extensive and important contracts. Nine years later he was appointed engineering surveyor to the Board of Trade for the Clyde ports, comprising the area from the Mull of Galloway to Oban. At his suggestion the system of granting certificates to engineers after examination was inaugurated, and for a little he was the sole examiner for Scotland. Retiring from the Board of Trade, he joined the firm of Messrs. David & William Henderson, shipbuilders and engineers, Partick, as a partner, and remained in that capacity for 15 years. He died at the age of 83.

Mr. Robson read his historical paper entitled "On the Advantages of Springs for Loading Government Safety Valves of Marine Boilers instead of Deadweight," before this Institution, on 23rd December, 1873. He started by saying, "The dear coal, high wages, and shortened hours of labour of the present time are acting to such an extent upon, and increasing, the first cost, the maintenance, and the expense of sailing our steam-vessels, that in some trades such vessels cannot be sailed with profit to their owners." How very like to-day, and yet to-day there is the additional burden of severe foreign competition.

Mr. Robson's paper was the outcome of efforts to induce

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the Board of Trade to approve of the use of spring-loaded valves, a large number of which he had made in the works of Messrs. D. & W. Henderson. Its publication aroused great interest and enthusiasm amongst members of the Institution, and it was proposed and seconded that a Committee be formed to collect data and forward a memorial to the Board of Trade in favour of the spring-loaded safety valve.

The Committee comprised the following members:—Messrs. Walter Brock, James Brownlee, J. L. K. Jamieson, Ebenezer Kemp, H. R. Robson, and David Rowan. The only gentleman whom present-day engineers will find a little difficult to locate is Mr. Brownlee. He was the proprietor or one of the partners of the City Saw Mills, an excellent mathematician, and a great friend of Prof. Macquorn Rankine. His bust may be seen in the Library of the Institution. The Committee were most indefatigable in their work, and the report on the results of their careful experiments and investigations was read on 27th October, 1874. From this report the following extracts are taken:—

1. The Committee are indebted to Mr. James Brownlee for that portion of the report which treats of the out-flow of steam through an orifice; for the exhaustive series of experiments made by him; for references to the various investigations which have been made upon the subject; and from the results so obtained, the rules for the size of safety valve orifices.

2. To Mr. David Rowan for experiments made by him to ascertain the pressure to which steam will rise in a boiler above the load pressure, when the valves are of the same size, having an area of half-an-inch per foot of grate surface, but at different pressures, the whole of the steam raised being allowed to pass away by the safety valves when unassisted.

3. To Mr. Walter Brock for experiments made by him regarding the strength and action of springs as applied to the loading of safety valves.

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The Committee's experiments in connection with the flow of steam are particularly interesting, and I reproduce in Fig. 4 the illustration that appeared in connection with the report. For full details of the experiment, I refer members to the report which is published in Vol. XVIII of the Institution's Transactions. One outstanding feature of the experiments was the confirmation of the theory that the same quantity of steam was discharged through an orifice from a higher pressure to a lower pressure as long as the lower pressure did not exceed 58 per cent. of the higher pressure. Thus the same quantity of steam will be discharged from a vessel at a pressure of 100 lbs. per square inch to atmosphere as from the same vessel and at the same pressure into a second vessel having a pressure of 58 lbs. per square inch.

In 1875 the Board of Trade sanctioned the loading of safety valves by springs, and their formula for valve size gave a decreasing area for the higher pressures.

From a careful perusal of Mr. Robson's paper, it appears that there were certain grounds for the objection raised by the Board of Trade to spring-loaded as against deadweight valves. It is obvious that as a spring is compressed it offers a greater resistance, whereas a dead weight theoretically can be moved any distance by the force that has initially produced motion; but in Mr. Robson's experiments he showed there was not much to choose between the two types in practice, although any difference was certainly in favour of the deadweight valve. The Board, however, were not warranted in insisting, as they did, that if spring-loaded valves were fitted to a boiler the working pressure must be reduced by the amount of the increased pressure during the accumulation trial; that is to say, if a boiler designed for 100 lbs. working pressure had a deadweight safety valve, the boiler could be worked at that pressure. If, however, a spring-loaded valve of the same size were fitted an accumulation trial must be conducted, and the working pressure of the boiler reduced below the designed pressure by

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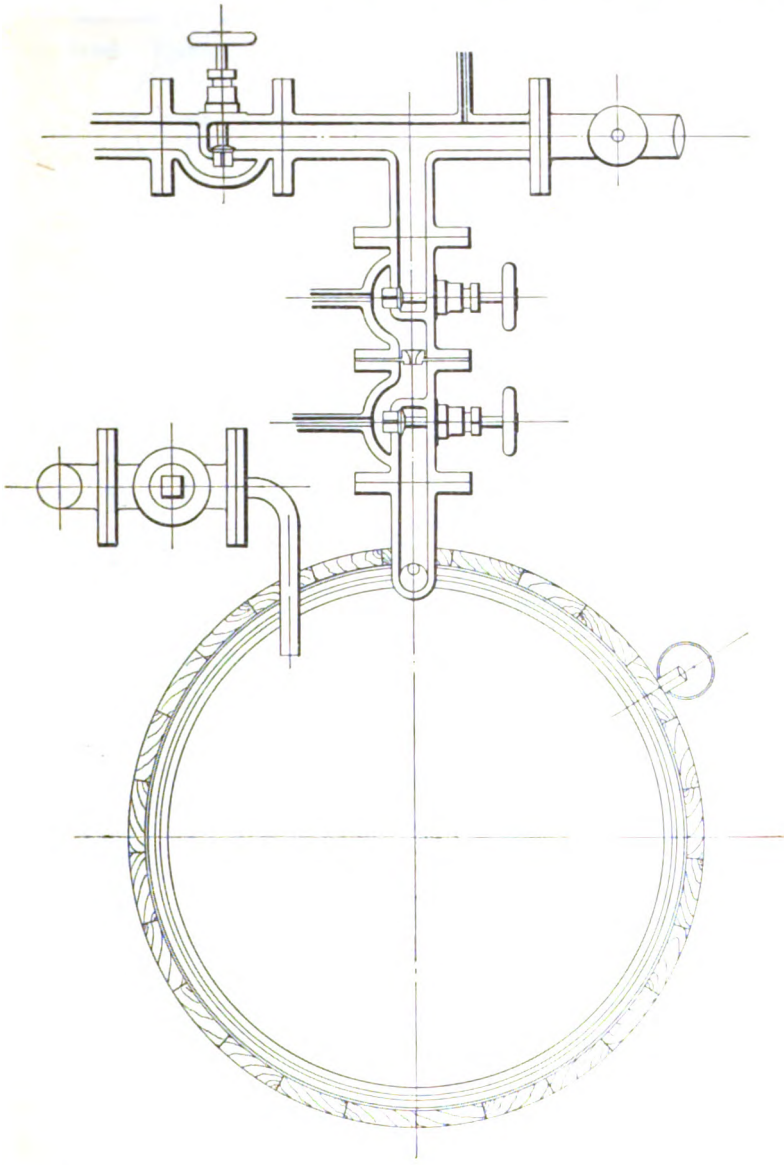

Fig. 4.

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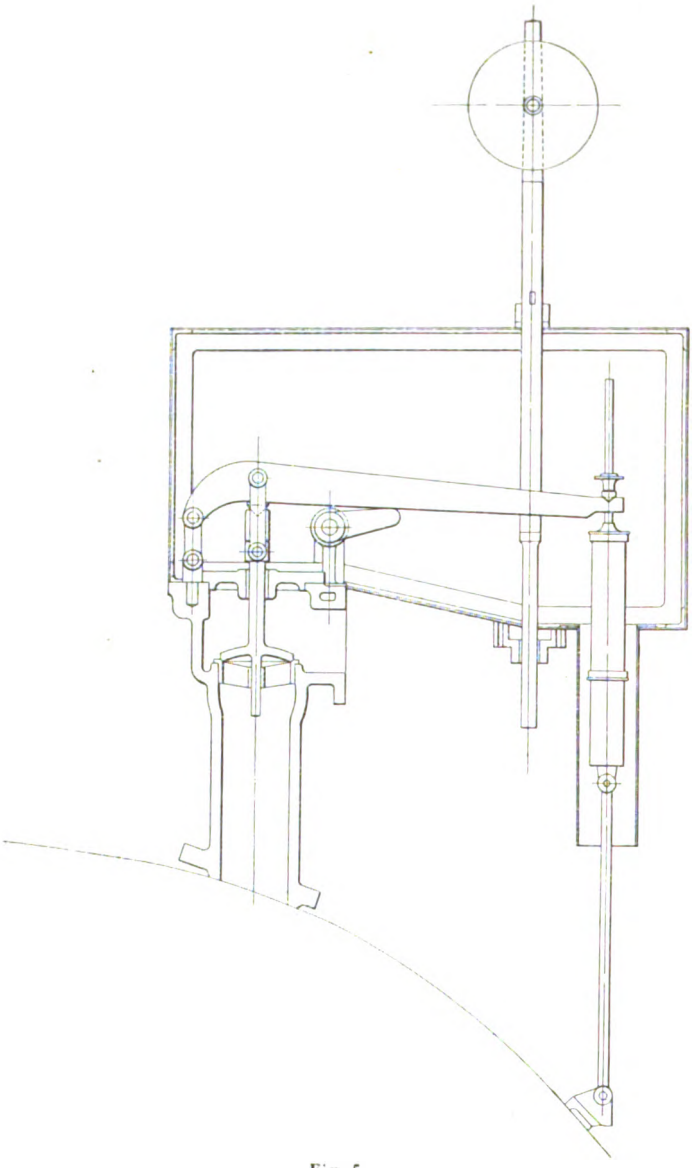

Fig. 5.

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the amount of the increase of pressure above 100 lbs. during the trial. This attitude, of course, was ridiculous.

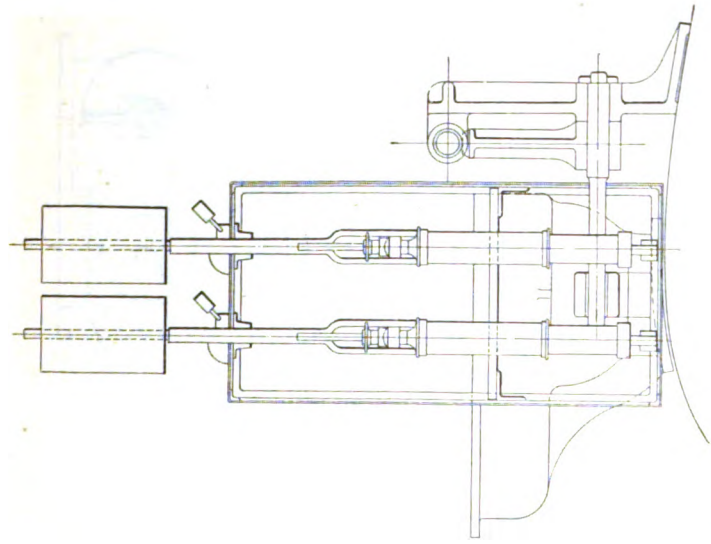
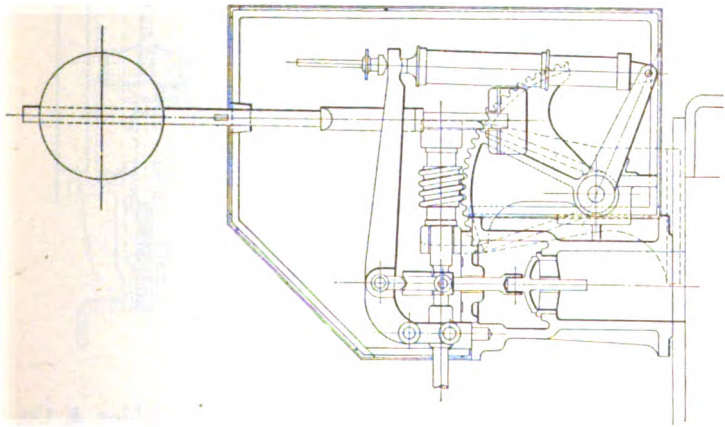


Fig. 6.



Figs. 5 and 6 show lever and spring-loaded valves constructed by Mr. Robson's firm. It should be noticed that at this time

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the Board of Trade insisted that weights should be provided in case of the springs breaking. Fig. 7 shows a direct

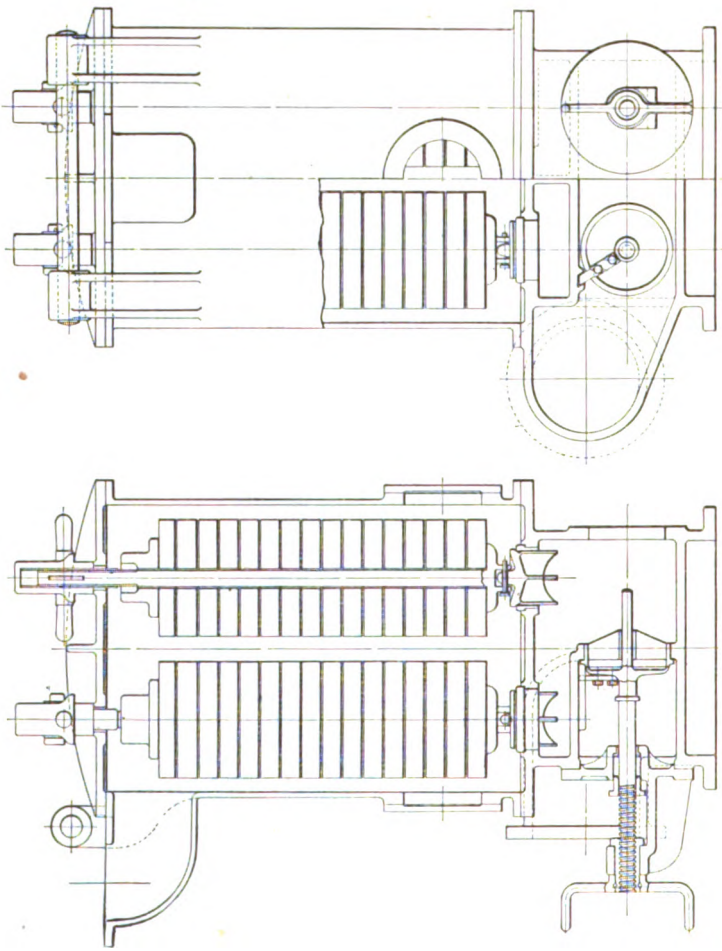

Fig. 7.

deadweight valve constructed by Messrs. John Elder & Co. (now the Fairfield Shipbuilding and Engineering Co., Ltd.). Figs. 8 and 9 also show a lever and deadweight valve, while

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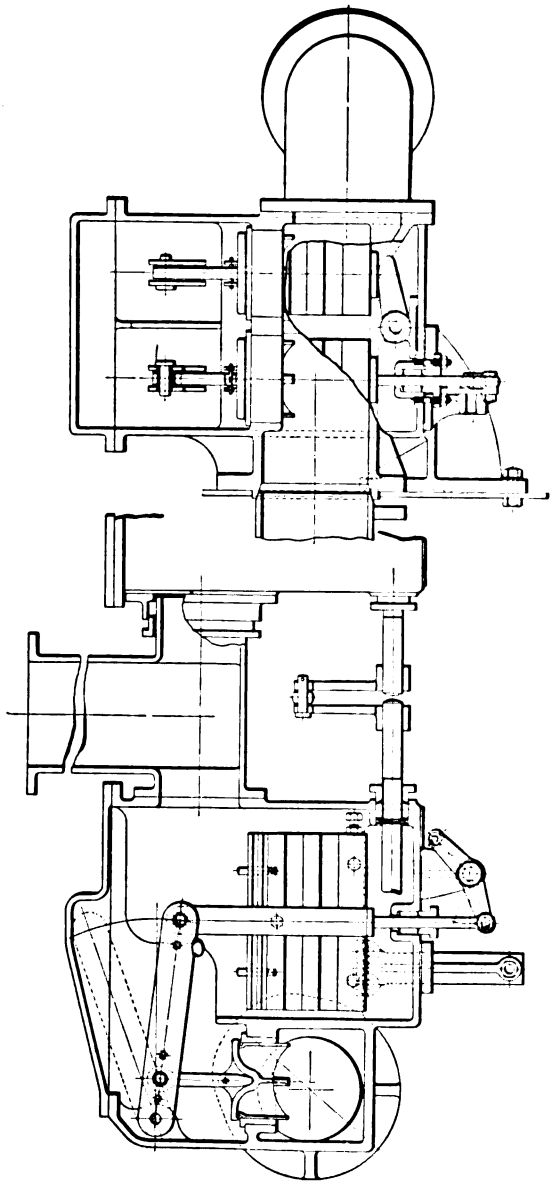

Fig. 8.

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Fig. 10 illustrates a spring-loaded valve for H.M.S's. "Hydra" and "Cyclops," also constructed by Messrs. John Elder &

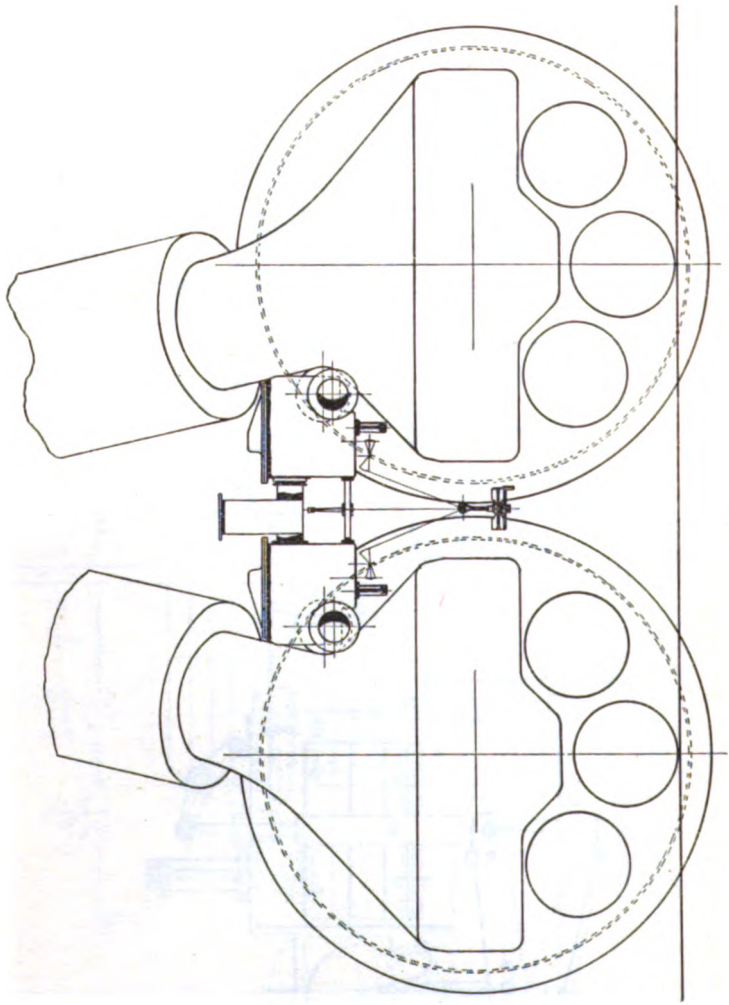

Fig. 9.

Co., and referred to in the discussion of Mr. Robson's paper by Mr. J. L. K. Jamieson, who was a partner in that firm.

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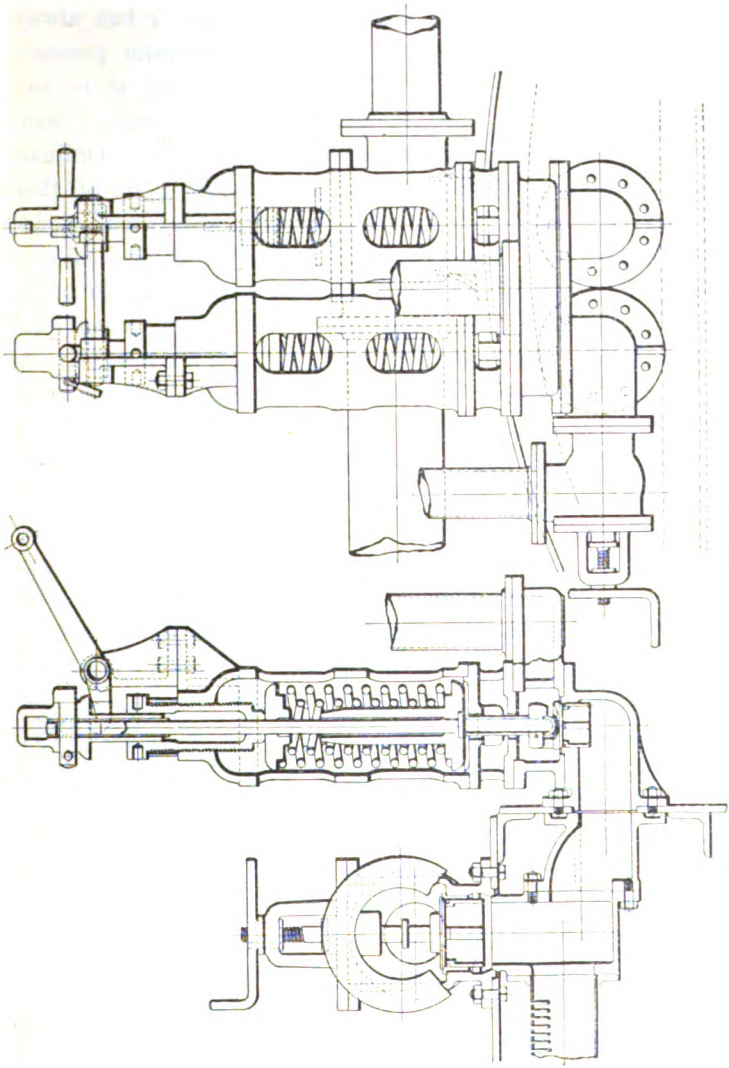

Fig. 10.

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In this connection Mr. Jamieson made out that the Admiralty were more progressive than the Board of Trade.

Before joining my firm some 18 years ago, I had always assumed that when passing steam at maximum pressure, safety valves lifted $\frac{1}{4}$th of their diameter; that is to say, that the edge area was equal to the disc area. Soon, however, I found this to be far from the truth. Ordinary direct spring valves only lift approximately $\frac{1}{24}$th of their diameter or, in other words, give an edge area of $\frac{1}{6}$th of the disc area. Consequently I gave a great deal of time and attention to the problem of designing a valve to lift to $\frac{1}{4}$th of its diameter. Ultimately the conclusion forced itself upon me that this could only be done satisfactorily on the relay principle of a small valve controlling a larger one.

In 1908 a number of British destroyers were fitted with oil-fired boilers, and when the accumulation trials took place, notwithstanding that the safety valve area had been increased in proportion to the higher calorific value of oil, the valves were not nearly large enough for their duty. Consequently, steps had to be taken either to make larger ones or to get the valves to lift higher. A considerable pressure was noticed in the waste-steam portion of the valve chests which prevented the valves from lifting the requisite height. In some cases slightly larger valves and much larger waste-steam pipes were fitted, and the accumulation trials were satisfactorily passed. In the case of H.M.S. "Cossack," built by Messrs. Cammell Laird & Co., Ltd., it was noticed that if the easing gear were operated a comparatively small amount the pressure could be kept within the accumulation allowance. It then occurred to Mr. J. Hamilton Gibson that the pressure in the waste-steam space of the valve might be used to lift it higher. He thereafter fitted a cylinder to the steam drum, and connected the easing lever to a piston inside the cylinder. A pipe led from the waste-steam space to the cylinder, so that the pressure on the piston assisted the valve. This arrangement is shown

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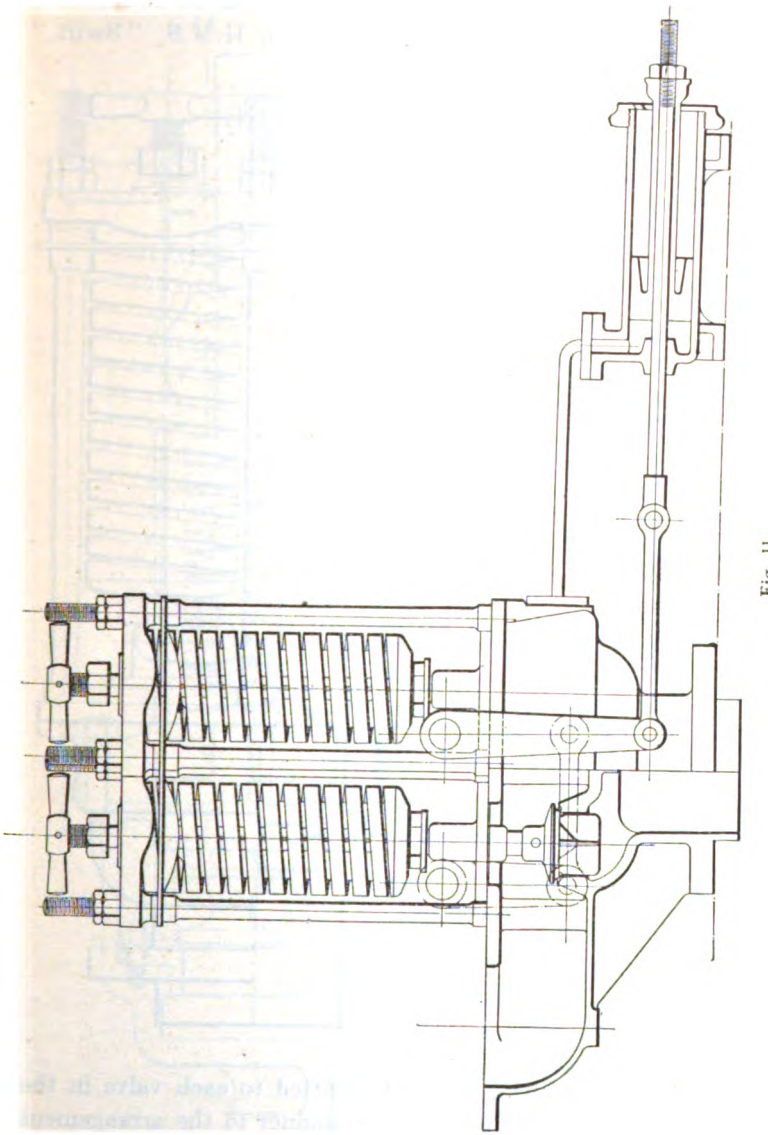

Fig. 11.

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in Fig. 11, and was quite successful, at least as far as accumulation was concerned. In the next vessel, H.M.S. "Swift,"

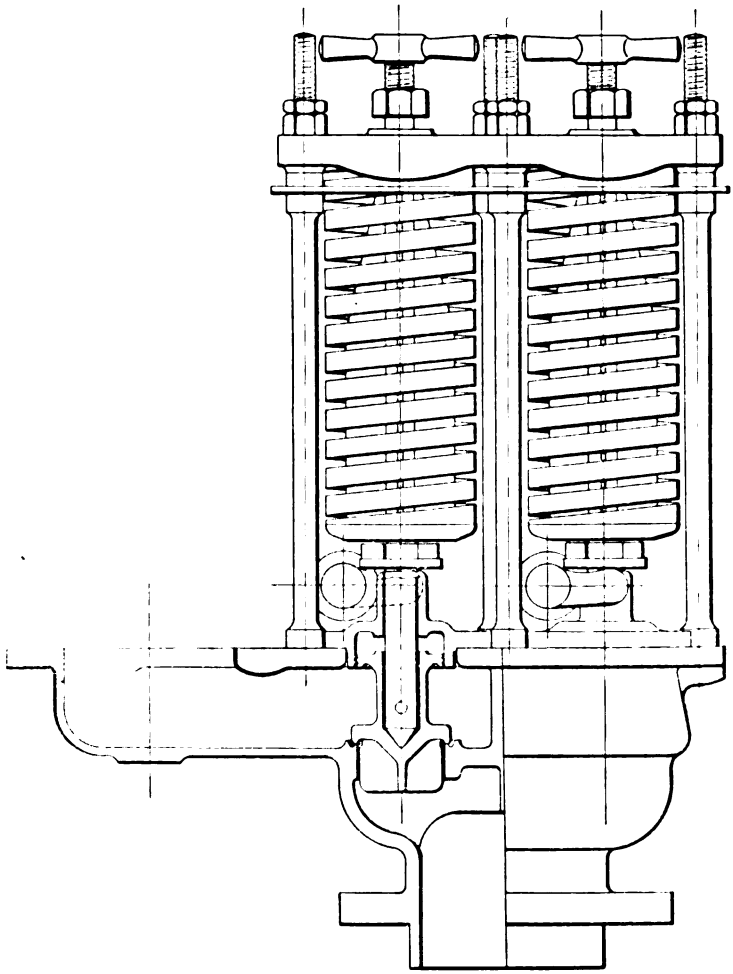

Fig. 12.

a balancing and lifting piston was fitted to each valve in the chest, and functioned in a similar manner to the arrangement in H.M.S. "Cossack." Fig. 12 illustrates this fitting.

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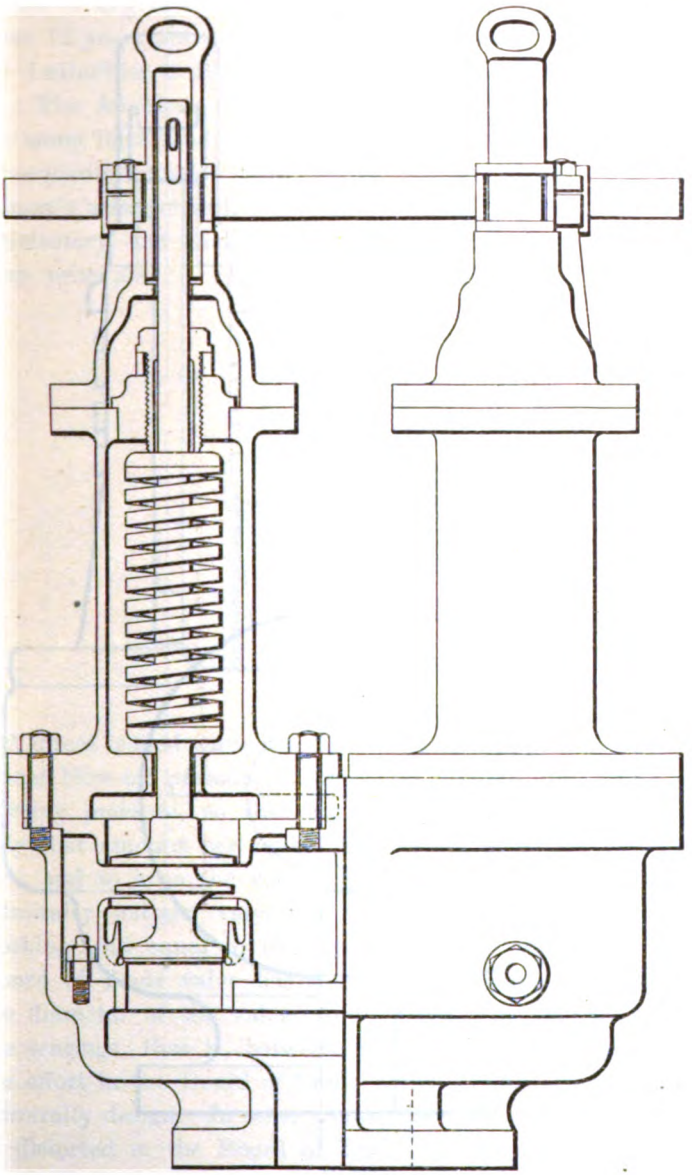

Fig. 13.

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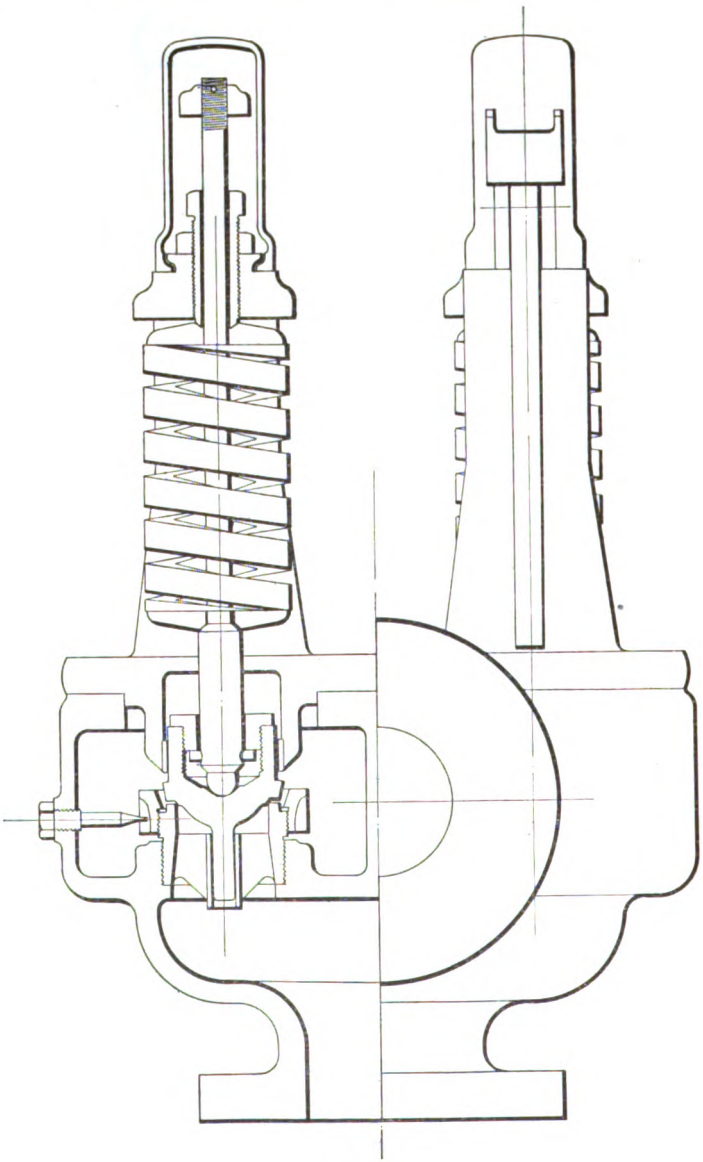

Fig. 14.

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French engineers, however, had adopted this arrangement some 12 years previously, and their adaptation was known as the Lethuillier & Pinel safety valve, which is shown in Fig. 13. The American Board of Trade safety valve was also on the same lines, and is shown in Fig. 14. Messrs. Cockburns subsequently made some valves in accordance with Mr. Gibson's arrangement, but, generally speaking, they were not satisfactory, and finally had to be replaced with valves on the relay principle.

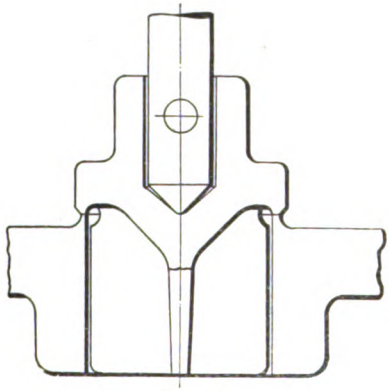

Fig. 15.

A direct loaded valve is a delicate piece of mechanism. The actual blow-off pressure is generally about 5 lbs. above the working pressure, so that at the working pressure there is only that amount per square inch to overcome all distortion, etc., and to keep the valve tight. Again, the direct loaded Admiralty pattern valve has a spring compression at the working load equal to the diameter of the valve, while the Board of Trade valve has a spring compression only $\frac{1}{4}$th of the diameter of the valve, so that per unit of distortion in the seatings, that is, between the faces, there is four times the effort in the Board of Trade design as compared with the Admiralty design. In other words, the seatings do not become so distorted in the Board of Trade safety valve. Distortion

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has always shown up more or less in Admiralty valves by a bad feather of steam at the waste-steam pipe, some 5 lbs. at least below the working pressure, and the larger the valve the worse the leakage.

Generally speaking, the form which the old deadweight valve took is shown in Fig. 15. When the spring-loaded valve was introduced, both the valve and seat were designed so that as soon as the former lifted a greater area was exposed to the steam to overcome the increasing resistance of the spring.

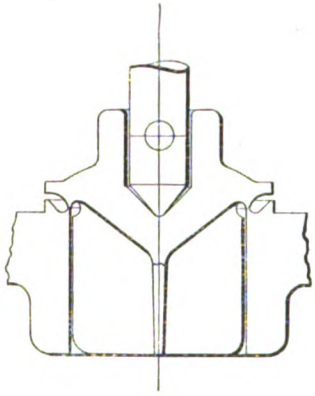

Fig. 16.

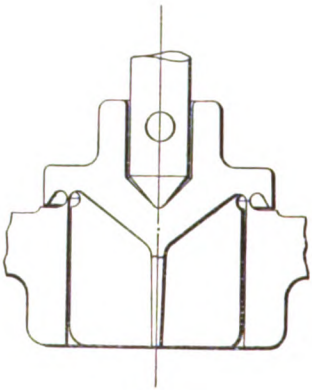

Fig. 17.

Fig. 16 shows one arrangement commonly known as the Cockburn design, while Fig. 17 shows a design adopted by Adams, of Manchester. With either of these arrangements the valve usually dances or pulsates; to this movement the term generally applied is "dirling." As the pressure drops, the valve takes to its seat during one of the pulsations, and thus cuts off the steam sharply and cleanly. This pulsation always shakes up the valve, and frees it from friction.

When Mr. Gibson adopted the balancing or lifting piston, he did away with the lifting device in the valve itself, as will be seen on examination of Fig. 12, with the result that it was most difficult to say at what point the valve had actually

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lifted, and still more difficult to say when it had shut properly. Friction affected the valve all the time, and generally it was still feathering at about 30 lbs. below the working pressure. Following the unsatisfactory functioning of this type of valve, the late Mr. Robert Cockburn and I introduced the relay or full-bore valve. This fitting is shown in Fig. 18, and an outstanding feature is the saving in weight.

In the group of British destroyers built in 1912, two tons were saved in the valve equipment on four boilers. It is now the standard naval fitting in all navies of the world, with the exception of Germany and the United States. It has also been adopted by the French shipping line, Compagnie Generale Transatlantique, in their new ships, and last year the 19 Lethuillier & Pinel valves on "La France," belonging to that company, were replaced by relay or full-bore fittings. In the beginning of 1914 it was tentatively approved by the Board of Trade for a steamer for the Cunard Co., which was to have been built by Messrs. Scotts', Greenock, but owing to the war she was never completed. After an exhaustive series of experiments had been conducted with this type of valve, it was found to be the most satisfactory for high steam-pressures in the region of 800 lbs. per square inch. As, however, I wish to confine myself more particularly to the mercantile marine valve, I shall not enlarge on this fitting.

Fig. 19 illustrates the more or less standard direct spring-loaded valve evolved since 1875, and which met the Board of Trade requirements for marine work. This arrangement is still in use. In 1919 Messrs. Cockburns started experiments on a high-lift type of valve, with the object of reducing the size and cost of valves. About this time also the British Marine Engineering Design and Construction Committee were deliberating on the valve question, and amongst other considerations they revised, hardly to its betterment, the formula for safety valves. The old formula $\frac{37{\cdot}5 \times G}{P}$ was based on the

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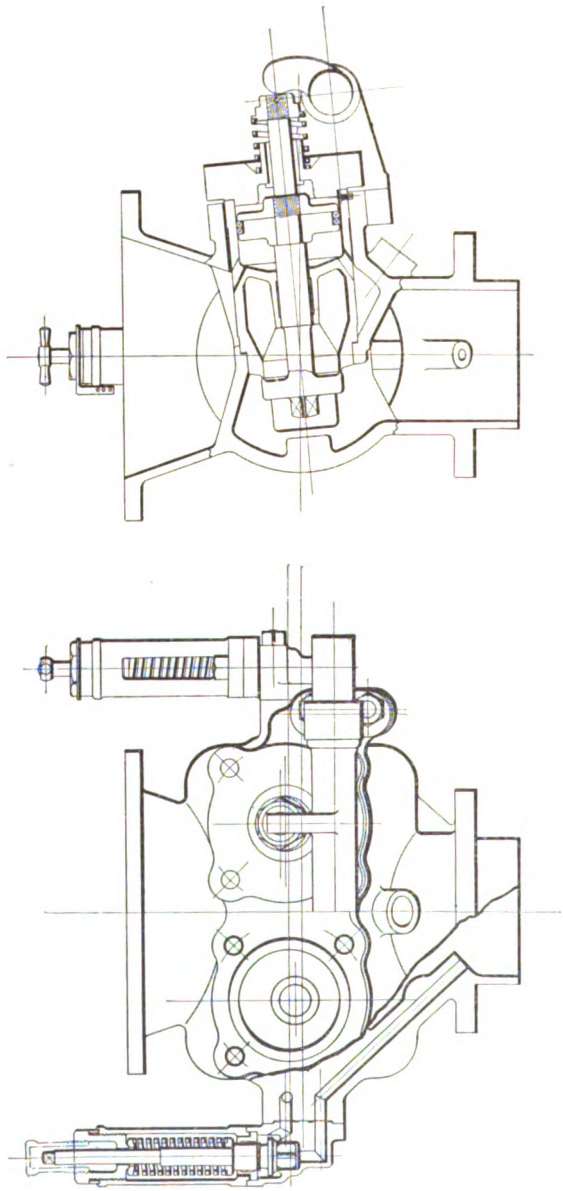

Fig. 18.

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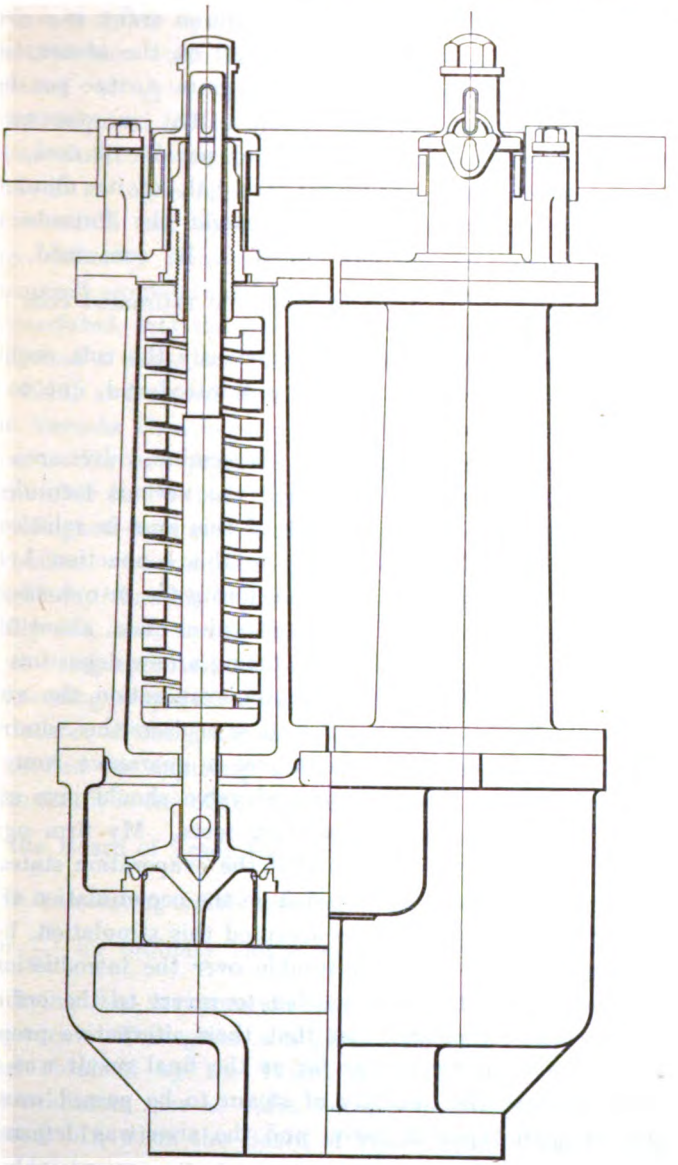

Fig. 19.

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quantity of steam that could flow through an orifice in a given time with a certain steam pressure, and on the assumptions that 20 lbs. of coal per square foot of grate surface per hour could be burnt with natural draught, that an evaporation of 8 lbs. of water might be expected per lb. of coal, and that the valve lifted approximately $\frac{1}{24}$th of its diameter. With the introduction of forced draught the formula was altered to allow for the extra coal to be consumed, and took the form $\frac{37{\cdot}5 \times G}{P} \times \frac{C}{20}$, C being the estimated coal consumption under forced draught. Obviously the rule required to be again changed when oil fuel was introduced, due to the higher calorific value of oil.

The prime factors necessary to determine valve area are evaporation and pressure. Through the various formulæ in use, engineers have come to think of this area in relation to grate surface or heating surface. In this connection I may mention an incident which occurred during the introduction of the full-bore safety valve to the light-cruiser class, about 1910. On the Admiralty tracings for this fitting a new departure was inaugurated in stating the maximum evaporation the valves were expected to cope with. For these cruisers the Admiralty asked the main contractors to secure a guarantee from the valve makers that this new type of valve should give entire satisfaction during the accumulation tests. My firm agreed to this guarantee, on condition that the evaporation stated on the tracings would not be exceeded on the accumulation trials. Three of the main contractors accepted this stipulation, but a fourth stated that, to avoid trouble over the introduction of this new fitting, they had decided to revert to the ordinary type of valve. I pointed out that their alternative proposal would make no difference as far as the final result was concerned, because the quantity of steam to be passed was the same for both types of valve, and the area was determined from the Admiralty regulation of so many square inches of

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area per 1,000 square feet of heating surface. As, however, the full-bore valve lifted a distance of $\frac{1}{4}$th of its diameter instead of $\frac{1}{24}$th as in the ordinary valve, the former only required to be $\frac{1}{6}$th of the area of the latter. The same duty, however, would be required from either valve, and if no agreement could be reached on this point my firm would ask to be relieved of all responsibility should any difficulty arise on the accumulation trial due to an increased evaporation being passed. The position was finally appreciated, and the full-bore valve was adopted.

I read a paper on "Safety Valves" before the Institution in 1914, and stated therein that it was to be regretted that the formulæ then in use did not embody the prime factors of evaporation and pressure. In the discussion which followed a member stated that "He did not see how safety valves could be designed from such a vague thing as evaporation. A maker of boilers, who wanted to get off lightly with the safety valves, might say that his boiler evaporated a good deal less than it really did, and, as the boiler was not made when the designs were being approved, the only way of checking the statements concerning evaporation was to call for the areas of the heating surface or of the grate surface." Now the quantity of steam generated is anything but vague in connection with the formulæ; it is one of the fundamental factors (although hidden) in the Board of Trade formula $\frac{37{\cdot}5 \times G}{P}$.

In calculating valve area for a given quantity of steam, I use $\frac{E}{4P}$ for ordinary valves which lift $\frac{1}{24}$th of the diameter, E being the evaporation per hour and P the absolute pressure. This gives a slightly larger area of valve than that obtained by the Board of Trade formula, and fixes the minimum size of valve for any quantity of steam to be passed. If, when the Board of Trade formula was first introduced, the quantity of steam had been taken as one of the

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factors, it would not have required modification when any change took place, either in fuel or methods of combustion.

When the British Marine Engineering Design and Construction Committee were considering the revision of safety-valve formulæ, I suggested to the chairman of the Committee that area of fire grate or fuel consumption was a better basis for valve design than that of heating surface. He replied that heating surface was a measure of efficiency, to which I agree, but maintain that fuel consumption is a more direct measure of the duty of the safety valve. I fully expected when the rules were published that there would have been some statement relative to the fuel consumption per square foot of heating surface, but this is not the case, as will be seen from the formula, which is $\frac{K \times H}{P}$ = area of valve, where K varies for different types of boiler and conditions of firing, H is the heating surface, and P the absolute pressure in lbs.

It is obvious that safety valves determined by the new rule can only pass the same amount of steam at the same pressure as one of corresponding size designed to the old rule. This being so, it is an easy matter, from a comparison of the two formulæ, to find a fuel value for the new formula. From the trials of a number of boilers I tabulated values of fuel consumption, although the varying ratio of grate to heating surface made the task somewhat difficult. I find that for Scotch cylindrical boilers, where K = 1·25 with natural or forced draught other than closed stokehold, the consumption per square foot of grate is in the region of 25 lbs. of coal per hour, the equivalent consumption per square foot of heating surface being ·62 lb. of coal. Again, for the same type of boiler with closed stokehold, the consumption of coal per square foot of grate is 30 lbs., the equivalent consumption per square foot of heating surface being ·75 lb., where K = 1·5. With oil, allowing an evaporation of 12 lbs. of water from 1 lb. of oil as against 8 lbs. of water from 1 lb. of coal, the quantity

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of oil burned per square foot of heating surface is ·5 lb. (a low consumption). In the case of water-tube boilers where K = 1·1 for natural draught, and 1·25 for closed stokehold and oil, the quantity of coal burnt per square foot of grate is 25 lbs. and 30 lbs. respectively, corresponding to a coal consumption per square foot of heating surface of ·6 lb. and ·7 lb. respectively, and in the case of oil, of ·47 (again a particularly low consumption for water-tube boilers). These are the figures for certain boilers which were fitted with valves made in accordance with the new rules. But the Committee should state what consumption of fuel per square foot of heating surface they had in view when the new rules were drawn up; naturally these figures should be worked to during an accumulation trial. I need only state that, if desired, 2 lbs. of oil could be, and has been, burnt per square foot of heating surface, and 1 lb. is an everyday occurrence in naval work.

The Committee had all the information necessary to produce an extremely simple formula, not necessarily in terms of evaporation, but of fuel consumption. The objection to both the new and the old formulæ is that they would require to be altered if a fuel of higher calorific value than oil were discovered or manufactured, whereas this would be unnecessary had they been directly based on evaporation. When coal is used as a fuel, and assuming an evaporation of 8 lbs. of water per hour per lb. of coal, the new formula would become $C \div \frac{P}{2}$, where C is lbs. of coal consumed per hour, and P the absolute working pressure. For oil the formula would be $C \div \frac{P}{3}$, where C is lbs. of oil consumed per hour, and P as before. These formulæ would be applicable to any type of boiler.

In the discussion on the report of the Institution in 1874, reference was made to a type of safety valve known as the Cockburn valve, which it was stated lifted to $\frac{1}{4}$th of its diameter. Fig. 20 is a reproduction of the valve as illus-

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trated in connection with the report. This was also known as the plate-below valve. I have never seen one of these valves spring-loaded as shown, but have seen many loaded with deadweights, and a short time ago one was returned to

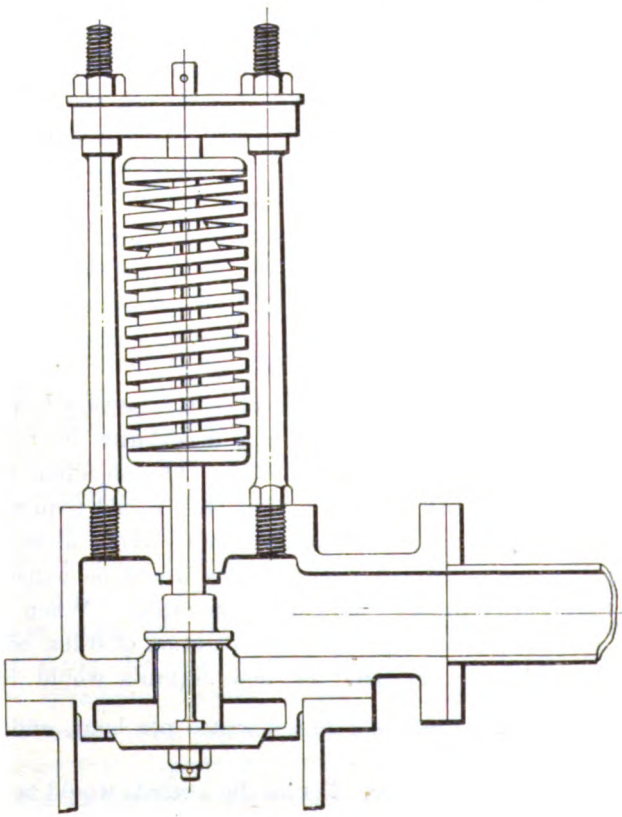

Fig. 20.

our works for repair. On putting it to the steam test it momentarily lifted to $\frac{1}{4}$th of its diameter, and there is no reason why deadweight valves should not do so, but it is most unlikely that a spring-loaded valve of this kind would lift that amount, particularly with a waste-steam pipe fitted.

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What I wish to make clear is that this plate-below valve would function in a similar manner to the valve and seat arrangement shown in Fig. 16. In both these designs, pressure in the waste-steam space would prevent their lifting properly.

In connection with the first destroyers fitted with oil fuel, it has already been stated that in the original valves there was considerable pressure in the waste-steam portion of the chest, and I shall refer briefly to this matter. If it is desired to have a constant pressure in the waste-steam portion of the chest or at the base of the waste-steam pipe, it is better for each size of ordinary valve to be fitted with a particular size of waste-steam pipe suitable for each boiler pressure. In the past the area of inlet and outlet in the valve chest was made equal to the area of the valve, or where there was more than one valve, the aggregate area of the valves. In a 4-inch single valve with a 4-inch inlet and outlet, twice as much steam passes through the valve at 200 lbs. as at 100 lbs., so of necessity the pressure in the waste-steam portion of the chest must be higher in the valves fitted for 200 lbs. A high waste-steam pressure causes back pressure on the valve, and prevents it lifting as high as it would with a lesser pressure; but, practically speaking, it does not necessitate a pipe of increased thickness.

It has been shown that, in the American Board of Trade safety valve, the Lethuillier & Pinel, and the valves of H.M.S's. "Cossack" and "Swift," back pressure was turned to good account. Unfortunately Mr. Gibson, in his valve, did away with the lifting device on the valve proper, and thus made the valve unsatisfactory in its action. He also made the piston integral with the valve, as was also done in the other two designs. Now this initiated a source of possible sticking, and it will be appreciated that the Board of Trade would not look kindly upon an arrangement of this sort, and rightly so.

In 1919 Messrs. Cockburns realised that the question of

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sticking or gagging required most careful consideration. Ultimately the fitting shown in Fig. 21 was evolved, possessing a new feature in that the valve lifted in the first instance as an ordinary valve. Whenever there was sufficient pressure in the waste-steam space of the chest, the secondary valve, or piston which was loose on the spindle, lifted and abutted the underside of the spring seating in the spindle. Until the piston lifted it acted simply as a valve with four webs, the piston portion being about $\frac{1}{8}$th inch below the bush or seating in the casing. If the piston stuck, the valve spindle moved through the piston, the piston taking the place of the bush in the bottom of the casing of the ordinary valve. Under this circumstance the valve could not lift so high, but still the area of escape was sufficient to meet all normal demands, that is to say, its capacity was about one-half of what it would have been if the piston had been functioning.

Trials were conducted on a water-tube boiler at Messrs. Yarrow's works in May, 1919, with a $2\frac{3}{4}$-inch double high-lift valve, at which there were present representatives of the Board of Trade, Lloyd's, etc., and various insurance companies. Subsequently the Board were approached to sanction the use of the fitting at a 50 per cent. reduction of area as compared with the ordinary valve. They, however, would only agree to a reduction in area of one-third, stating at the same time that after 12 months' service the matter might be reconsidered. An outstanding incident brought out its superiority over the ordinary safety valve. After valves of the ordinary type had been fitted to a large liner, it was decided to change from coal to oil fuel. Subsequently the accumulation trial was carried out, and a higher accumulation of pressure took place than was desired. The ship had 12 boilers, with 12 leads of waste-steam pipe to the two main steam-pipes up the funnels. The fitting of larger valves and waste-steam pipes would have been a costly procedure, so the valves were converted to the high-lift type, and on the trial

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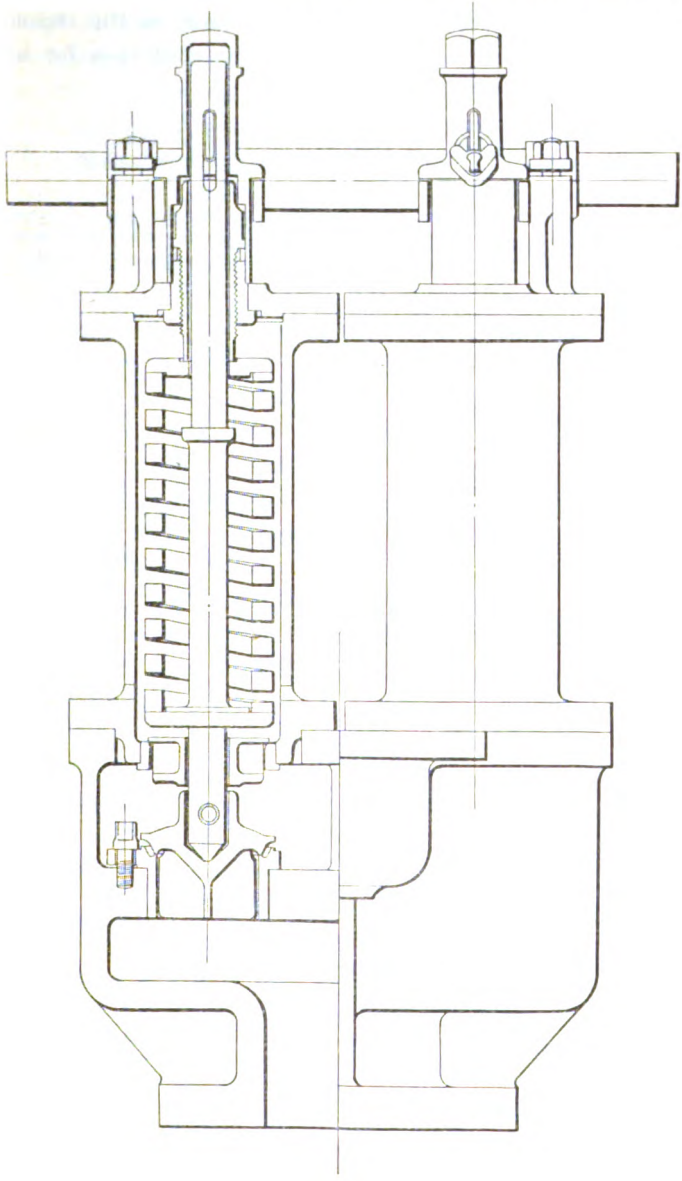

Fig. 21.

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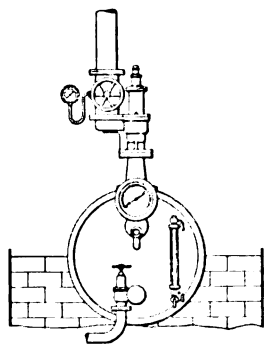
the maximum accumulation of pressure was in the region of 4 per cent. This trial at once demonstrated that for high-

REPORT OF
ACCUMULATION TEST, WITH 60% BACK PRESSURE, OF
STANDARD 2" HIGH LIFT DOUBLE SPRING SAFETY VALVE

WITH NORMAL EXHAUST PRESSURE OF 9 LBS/IN². DURATION OF EACH TRIAL - 15 MINUTES. TRIALS WERE CONTINUOUS, STOP VALVE BEING SCREWED DOWN AT THE END OF THE FIRST 5 MIN. TILL 120 LB/IN² WASTE STEAM PRESSURE WAS ATTAINED, AND SECOND TRIAL READINGS TAKEN

	1ST TRIAL	2ND TRIAL
SIZE OF VALVE	2" DIA	2" DIA
BOILER PRESSURE	200 LB/IN²	200 LB/IN²
EXHAUST "	9 "	120 "
AVERAGE ACCUMULATION PRESSURE	202 "	198 "
" BACK "	12 "	120 "
TOTAL EVAPORATION PER HOUR	9,588 LBS	12,408 LBS
LIFT OF VALVE	5/32 FULL	9/64 BARE
ACCUMULATION	2 LB/IN²	EVAPORATION PASSED AT 2 LB/IN² BELOW WORKING AND BLOW-OFF PRESSURE

VALVE LIFTED AT - 200 LB/IN²
" SHUT DOWN " - 195 "



TESTING ARRANGEMENT

Fig. 22.

lift valves on this principle the area of the waste-steam pipe need only be equal to the combined area of the valves. It

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appeared at once that a considerable saving in first cost in waste-steam pipes could thus be effected.

The introduction of high-lift valves virtually reduced the areas of valves and waste-steam pipes by one-third. Lloyd's, however, thought it desirable to keep waste-steam pipes up to the full area. Mr. Clarke, late chief engineering surveyor to Lloyd's Register in Glasgow, who took a great interest in the high-lift safety valve, reminded me that I once held the view that the flow of steam through the waste-steam pipe was not affected until the external pressure was from 58 to 60 per cent. of the internal pressure, and suggested that a test might be conducted to prove this.

Accordingly, a stop valve of 5 inches bore was fitted to the waste-steam pipe of a 2-inch single high-lift valve with a waste-steam pipe of 5 inches bore. The first test was conducted with a perfectly free exhaust. On a second test the stop valve on the waste-steam pipe was closed down until a back pressure of 60 per cent. of the boiler pressure was attained. The result was that actually a much higher evaporation was passed, this, of course, being due to the greater back-pressure lifting the particular type of valve, and giving a greater egress orifice at the point where restriction occurs, namely, the edge area of the valve proper. Fig. 22 gives a full report of the experiment, which was witnessed by Mr. Clarke in 1923, and reported upon by him to Lloyd's, who were very interested in the results. Before, however, approving of a reduction in waste-steam pipe area, they asked that a test might be conducted with an actual length of waste-steam pipe at the reduced area, to see if this would have any material effect. This led to a comparative trial being made between the 2-inch single high-lift valve with a 5-inch and a 2-inch waste-steam pipe respectively. Fig. 23 gives the tabulated results. Approval was subsequently given that high-lift valves of this type could be fitted with waste-steam pipes of 1·1 times the combined area of the valves.

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REPORT OF
ACCUMULATION TESTS OF HIGH LIFT SPRING SAFETY VALVE

WITH DIFFERENT WASTE STEAM AREAS

TO DEMONSTRATE THE EFFICIENCY OF HAVING THE WASTE STEAM AREA 1.1 TIMES THE ACTUAL AREA OF THE HIGH LIFT VALVES THEMSELVES AS AGAINST AN AREA OF 1.1 TIMES THE AREA OF THE ORDINARY SAFETY VALVES AS DETERMINED BY THE RULE

BABCOCK WATER TUBE BOILER HEATING SURFACE – 735 Sq FT
GRATE AREA – 16·25 " "

2" HIGH LIFT DOUBLE SPRING SAFETY VALVE (WITH ONE VALVE GAGGED)

DURATION OF EACH TRIAL 30 MINUTES
WORKING PRESSURE – 200 LB/□" BY GAUGE
EXHAUST " – LB/□" " "

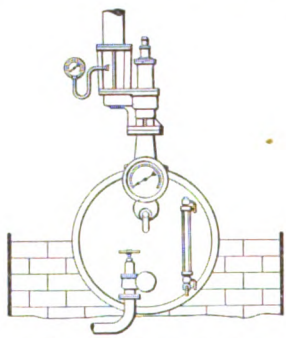
ALL VALVES & CONNECTIONS ON THE BOILER SHUT DOWN EXCEPT STEAM TO WEIRS FEED PUMP

VALVE SET TO BLOW OFF AT 200 LB/□"

TRIAL WITH WASTE STEAM 2" BORE
(APPROX 1.1 TIMES THE ACTUAL DISC AREA OF THE VALVE)

START – 2·15 P.M.

TIME	PRESSURE BOILER	PRESSURE EXHAUST	LIFT OF VALVE
2·16	198	18	1/16 F
17	198	19	1/16 F
8	198	21	3/64
9	199	25	3/64
20	200	25	3/64 F
1	200	25	3/64 F
2	200	25	3/64 F
3	200	23	3/64 F
4	200	23	3/64 F
5	200	22·5	3/64 F
6	198	17	1/16 F
7	197	16	1/16
8	197	16	3/64 F
9	197	12·5	3/64 F
2·30	195	12·5	3/64 F
1	195	20	1/16
2	195	20	1/16
3	195	20	1/16
4	195	20	1/16
5	195	20	1/16
6	195	20	1/16
7	195	15	3/64 F
8	195	15	3/64 F
9	195	14	3/64 F
2·40	195	16	3/64 F
1	195	17·5	1/16
2	195	15	3/64 F
3	195	14	3/64 F
4	195	12	3/64 F
2·45	195	12	3/64 F



TESTING ARRANGEMENT

TRIAL WITH WASTE STEAM 5" BORE
(MUCH IN EXCESS OF 1.1 TIMES THE ACTUAL DISC AREA OF THE VALVE)

START – 12·46 P.M.

TIME	PRESSURE BOILER	PRESSURE EXHAUST	LIFT OF VALVE
2·17	198	2	3/64 S
8	198	"	3/64 S
9	196	"	1/16 S
20	195	"	1/16 S
1	195	"	1/16 S
2	195	"	1/16 S
3	195	"	1/16 S
4	197	"	1/16 S
5	197	"	1/16 S
6	197	"	1/16 S
7	197	"	1/16 S
8	198	"	1/16
9	198	"	3/64
2·30	198	"	1/16
1	199	"	1/16
2	199	"	1/16
3	199	"	1/16
4	199	"	3/64 S
5	199	"	3/64 S
6	199	"	3/64 S
7	199	"	3/64 S
8	199	"	3/64 S
9	199	"	1/16
2·40	197	"	1/16 S
1	195	"	1/16 S
2	200	"	3/64 S
3	195	"	1/16 S
4	195	"	1/16 S
5	198	"	1/16
2·46	195	"	1/16 S

BOILER	TRIAL WITH WS 2" BORE	TRIAL WITH WS 5" BORE
EVAPORATION (DURING TRIAL)	2203·5 LB	1977·5 LB
" PER HOUR	4407 "	3955 "
COAL CONSUMPTION (FROM TRIAL)	252 "	252 "
" " PER HOUR	504 "	504 "
COAL/SQ FT G.R. / HOUR	31 "	31 "
WATER/SQ FT H.S. / HOUR	6 "	5·4 "
MAXIMUM BLOW-OFF PRESS	200 LB/□"	200 LB/□"
ACCUMULATION	NIL	NIL
CAPACITY OF PUMP – DIA OF CYL 9" DIA OF RAM 3⅝ STR 6	AVERAGE DOUBLE STROKES PER MIN – 44	

NOTE :– THE HIGHER EVAPORATION IN TRIAL WITH 2" WASTE STEAM PIPE WAS DUE TO A THICKER FIRE AT COMMENCEMENT

THIS TRIAL DEMONSTRATED THAT THE PRESSURE IN THE WASTE STEAM SPACE, DUE TO THE REDUCED SIZE OF PIPE, WAS BENEFICIAL IN AS MUCH AS A HIGHER EVAPORATION WAS PASSED WITH NO INCREASE IN THE BOILER PRESSURE.

Fig. 23.

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Subsequently, a further reduction of valve area was considered, but before approaching the Board of Trade on the matter it was decided that the design in Fig. 21 should be modified, and the arrangement shown in Fig. 24 was

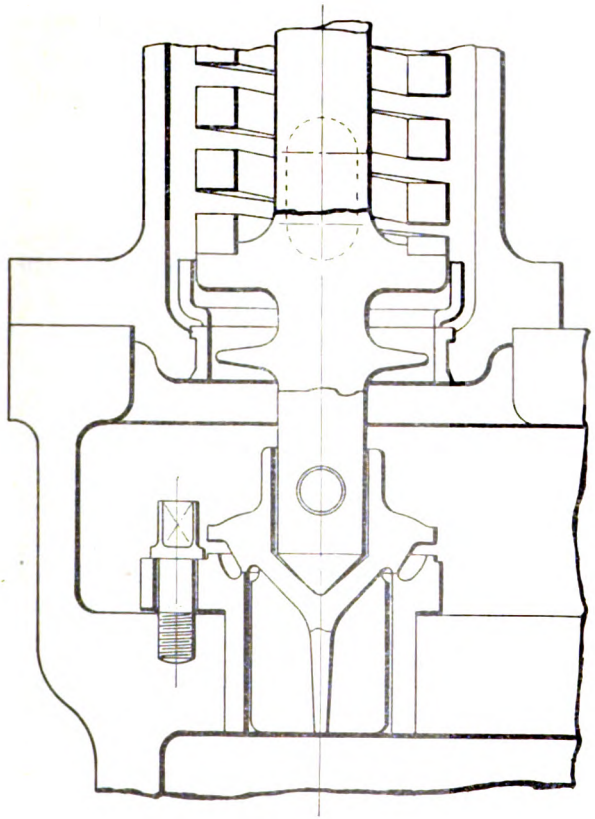

Fig. 24.

developed. As far as safety is concerned, it will be appreciated that this valve is not only an improvement on the one shown in Fig. 21, but is a distinct improvement on the ordinary valve. In the ordinary valve, Fig. 19, it is essential that large clearance be given between the bush in the bottom of the

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spring casing and the valve spindle, for if the spigot on the bottom of the casing is a slack fit in the chest to an extent greater than this clearance, the valve might function quite satisfactorily when first fitted, but care must be exercised in case of reassembling of parts after an overhaul, otherwise the valve might be rendered inoperative. The large clearance given between the diaphragm on the spindle and the bush in the casing in Fig. 24 prevents any possibility of trouble arising from sticking.

With a view to obtaining the Board of Trade's sanction to use this design with a 50 per cent. reduction of area of valve and waste-steam pipe below that required for ordinary valves, it was decided to run comparative tests with the ordinary and improved high-lift valves. To this end the valve shown in Fig. 25 was designed and developed. The difference between this form and that illustrated in Fig. 24 is that if the diaphragm in the former seizes it only affects the floating ring, and the valve proper can still function on the high-lift principle, whereas in the latter, if the diaphragm from any source jams in the bush, the fitting becomes inoperative. The whole position might be summed up shortly in the statement that the valve as shown in Fig. 25 has a two-to-one chance as compared with the fitting shown in Fig. 24, which has only an even chance. Comparative trials were carried out in 1925, and the results are tabulated in Fig. 26. These trials were conducted before representatives of the Board of Trade, Lloyd's, British Corporation, and Bureau Veritas. Mr. Barr, senior engineering surveyor of the British Corporation, stated that he was quite satisfied with the results, and subsequently official approval was given by that Society. The Bureau Veritas next intimated their approval. The Board of Trade stated, however, that they did not think the tests were quite conclusive, and Lloyd's were of the same opinion. The former instanced that the 1¾-inch waste-steam pipe was more than 1·1 times the area of the 1½-inch valve, the actual increase

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of area being 1·386 times, which was the nearest size of commercial pipe at that time available, and, further, that the satisfactory functioning of the valve depended upon the high

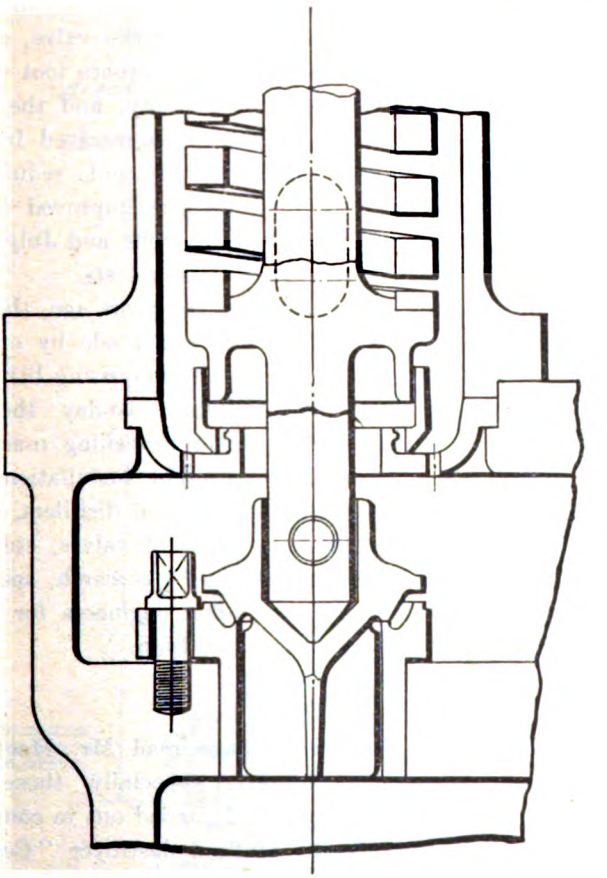

Fig. 25.

back-pressure shown in the tabulated results. It was pointed out to the Board that the valve did not depend upon a high back-pressure for its action, and, further, that the trials were comparative, and an exceptionally high rate of fuel consump-

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tion had been obtained, namely, 65 and 80 lbs. of coal per square foot of grate respectively, on two trials, whereas 30 lbs. was the normal consumption for the accumulation trials. A further trial was carried out on 10th May last, with the waste-steam pipe exactly 1·1 times the area of the valve, and the rate of coal consumption was 30 lbs. per square foot of grate per hour. This trial was very satisfactory, and the results are tabulated in Fig. 27. Approval was received from the Board of Trade and Lloyd's to a 50 per cent. reduction in valve and waste-steam pipe area for the improved form of high-lift valve, as shown in Fig. 25, in June and July of this year, subject to satisfactory accumulation tests.

At the inception of this Institution, 67 years ago, the whole of the machinery on board a vessel was made by one contractor, and was comparatively simple, comprising little more than the main engines and boilers. To-day there are manufactured by specialists the main propelling machinery, boilers and boiler fittings, forced-draught installations, feed and air pumps, condensers, evaporators and distillers, electric lighting installations, and various types of valves, etc. This change has been brought about chiefly by research, specialisation, and the incessant demands upon engineers for greater efficiency and economy in marine propulsion.

Discussion.

Mr. J. Hamilton Gibson: I have read Mr. MacNicoll's paper with considerable interest, especially those parts referring to the experiments which I carried out in connection with the safety valves of the oil-fired destroyer "Cossack" in 1908, and which have led, by a gradual process of evolution, to the very efficient high-lift valve of the present day. H.M.S. "Cossack" was the first oil-fired destroyer built by Messrs. Cammell Laird & Co., and no misgiving was felt concerning the size of safety valves until trouble was experienced in passing the Admiralty accumulation tests. The vessel was rapidly

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REPORT OF

OFFICIAL TEST

TO ASCERTAIN THE BACK PRESSURE IN WASTE STEAM PIPE

WITH COAL CONSUMPTION TO SUIT THE SIZE OF VALVE DETERMINED BY THE RULE, AND WASTE STEAM PIPE AREA 1·1 TIMES THE AREA OF THE VALVE

BABCOCK WATER TUBE BOILER – HEATING SURFACE – 735 SQ FT
GRATE AREA – 16·25 " "

CARRIED OUT AT MESSRS COCKBURNS LTD'S WORKS – CROOKNALD

10TH JUNE 1925

TO SUIT THIS SIZE OF VALVE, THE BOILER WAS FEED AT THE RATE OF 30·3 LBS OF COAL PER SQ FT OF G.A
i.e. 41 LBS OF COAL EVERY 5 MINUTES

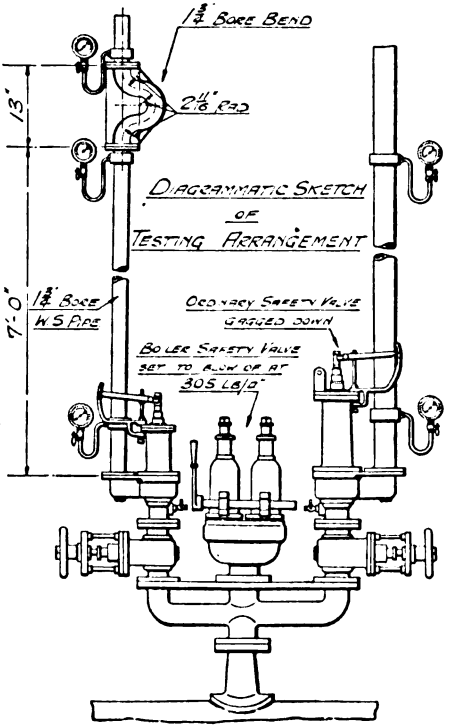

Fig. 27.

/FT
TY VALVE
·M
NUTES

PRESS IN PIPE BEFORE BEND	DIA OF VALVE
10	1/32"
9	1/32"
5	5/64"
2	1/16"
5	5/64"
5	5/64"
3	1/16"
LOSED DOWN	
3	1/16"
3	5/64"
3	5/64"
2	1/16"
3	5/64"
5	5/64"
6	5/64"
6	5/64"
5	5/64"
3	5/64"
OSED DOWN	
2	1/16"
3	5/64"
4	5/64"
5	5/64"
5	5/64"
3	5/64"
10	1/32"
10	1/32"
10	1/32"
8	1/32"
10	1/32"
10	1/32"
9	1/32"
5	5/64"
4	5/64"
3	5/64"

STOPPED, BUT THE FIRING WAS KEPT UP A FURTHER 5 MINUTES
COAL, AND GIVE THE CORRECT
ATER

1728	LBS
2064	"
287	"
492	"
6	"
30·3	"
4	"
5/64	
25·5	LB/□"
45	"
5	"
94	"
195	"
NIL.	

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approaching completion, and time did not permit of elaborate experiments. As a matter of fact, larger safety valves, with much bigger steam chests and waste-steam pipes, were hurriedly put in hand, but were not eventually fitted.

Luckily Eng.-Com. E. W. Liversidge (now Rear-Admiral, retired), who was Admiralty Overseer at the time, appreciated the true cause of the difficulty, namely, that it was the pressure above the valves when blowing off which prevented them from lifting to the required amount. To our surprise this pressure was found to be as much as 50 lbs. per square inch at 200 lbs. boiler pressure, although the waste-steam pipe was short and of ample area. I knew, of course, from the 58 per cent. rule, that there was nothing to be gained by increasing the size of the waste-steam pipe. But I found that a very slight movement of the easing gear in augmenting the lift of the valves would keep the accumulation down below the required limit; and the obvious thing to do was to make use of the surplus pressure above the valves for this purpose, as shown in Fig. 11.

It was a make-shift arrangement, but it proved the principle. Naturally an extraneous fitting of this kind could not be accepted as a permanency, so the balance-piston arrangement, as shown in Fig. 12, was fitted, and the vessel passed into service. Some time afterwards, I understand, full-bore valves were substituted. I mention this because it would appear from the paper that the outside cylinder and piston operating the easing gear was retained.

Meanwhile H.M.S. "Swift," a much bigger job, was approaching completion, and her accumulation tests were imminent. New valves with balance pistons, and new covers forming loosely-fitting cylinders for the latter, were ordered, the lips being retained on the valves. The accumulation was just exceeded, showing either that the balance pistons were too small, or alternatively that the area of the top of the valve was too great. The easiest thing to do was to reduce the

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Mr. J. Hamilton Gibson.
lip; and, as it happened in this case, it was necessary to remove the lip entirely to pass the accumulation tests.

Feathering after blowing off was noticed even at that time, but we were used to the same thing in ordinary spring-loaded valves, and a light blow with the hand on the top of the spindle sufficed to stop the feathering. I am afraid that nobody appreciated the full significance of the flutter in closing. It was thought that the function of the lip was merely to assist in opening; and the elimination of flutter, or "dirling," as described on page 134, was looked upon rather as an advantage, because of its comparative quietness. This was particularly evident in a subsequent test of a similarly-fitted triple safety-valve in a torpedo boat. Even with two valves gagged, and all oil burners going full out, the remaining valve passed all the steam without exceeding the specified accumulation. The valve lifted quietly, remained steady, and closed quietly—apparently an ideal test; but it continued feathering until the boiler pressure had dropped 35 lbs. Obviously something had to be done to make the valve close promptly, and the restoration of the lip was the obvious thing to do, with, of course, a balance piston of corresponding area. The subsequent stages in the evolution of the now well-known high-lift valve are clearly set out in Mr. MacNicoll's paper, and he is to be commended for his persistence, and congratulated on the final result.

It is indeed a triumph to have succeeded in producing a safety valve with a 50 per cent. reduction of area as compared with an ordinary valve, and to be on the point of having it accepted and approved by all the registration societies. I believe I was instrumental in getting the Board of Trade to accept the first high-lift safety valve for the mercantile marine, although this had only a 33 per cent. reduction of area. I am, therefore, particularly interested and gratified to know that the simple improvement which circumstances forced upon me 15 years ago has had such far-reaching results.

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Mr. John Dow.

Mr. JOHN DOW (Member): I think evaporation should have been taken into account in formulating the rule. There is a well-known formula for the quantity of steam which will escape through a hole one square inch in area, and it provides a very useful method for determining the amount of steam which can escape through a safety valve. Taking the absolute pressure at, say, 100 lbs., then the amount of steam which escapes per minute from a closed vessel through a hole one square inch in area is 75 lbs. Regarding the Board of Trade formula, $\frac{37{\cdot}5 \times G}{P}$, where G represents the grate surface of the boiler, P the absolute pressure in the boiler, and 37·5 a multiplier, which is supposed to give the area of the safety valve required for a given pressure and grate surface, if the grate surface is 100 square feet and the absolute pressure 100 lbs., the area of the safety valve would then be 37·5 square inches. Mr. MacNicoll has evolved and uses a formula $\frac{E}{4P}$, the lift of the valve being $\frac{1}{24}$th of the diameter. For the valve to be full open the lift should be $\frac{1}{4}$th of the diameter, so that $\frac{1}{24}$th is only $\frac{1}{6}$th of the full opening of the valve. That is, the capacity is $\frac{1}{6}$th of what the valve would give if it were full open. I should like Mr. MacNicoll to explain how he arrived at this formula $\frac{E}{4P}$.

I witnessed the experiments which took place in April and June last at Messrs. Cockburns' works, when a very interesting device was used for measuring the actual lift of the valve. No exception could be taken to the arrangements made for these tests, and the quantities of steam liberated, as shown in the table, could not be denied.

I agree with Mr. MacNicoll that it is important, especially with the use of oil fuel, that the quantity of fuel used should be specified at the tests, because if as much as 1 or 2 lbs. of fuel are to be used, as mentioned at the end of the paper, then I should hardly care to be present.

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Mr. James O. Baird.

Mr. James O. Baird (Member): I should like to relate an incident from my own experience bearing on the question of safety-valve area in relation to steam pressure.

The Company whom I served installed a steam plant of a single unit to supply steam to an existing plant where the steam was used for process work with widely varying demand. The steam pipes in this plant could not safely be used at a pressure above 80 lbs., but the boiler, with a view to future developments, was made for 160 lbs. pressure, and the safety valve (deadweight) was loaded to blow off at 80 lbs.

Originally fired with a low-grade tar, it was decided to change to a mechanical stoker with coal as fuel. After installation, I proceeded to run an efficiency trial as near as possible to capacity. The load varying greatly, as mentioned above, I decided to fire and feed steadily, and let the steam blow off. Before long I saw the pressure was rising rapidly, and I had to slow down. This was, of course, due to the fact that the safety valve was insufficient in area to pass all the steam generated at 80 lbs. pressure, though of ample area if the boiler was worked at 160 lbs. This had escaped the notice of the makers, the insurance company, and ourselves, but I can assure you that it was not long before the valve area was increased. This was done by putting a Y pipe on the boiler stool, and adding a second valve of the same area as the other but loaded slightly higher.

With references to coal consumption, Mr. MacNicoll gives the figure of 25 lbs. per square foot of grate. Is this not rather low? I have regularly fired boilers with a chain grate and natural draught at a rate of 28 lbs. of coal per square foot of grate.

Mr. James Barr (Member): No man knows more, and I think no man has ever known more, about safety valves than Mr. MacNicoll. Both in its historical and technical aspects, the paper is a most valuable contribution. Mr. MacNicoll has

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Mr. James Parr.

shown how, from the fact that marine steam propulsion was first applied to vessels making smooth-water passages, the deadweight safety valve became the standard, and what difficulties had to be overcome before sanction could be obtained for the use of the more efficient spring-loaded valve. This part of the paper is specially interesting to members of this Institution because of the active part taken by the Institution, and by individual members, in the investigations and in the agitation which at length succeeded in securing acceptance by the Board of Trade of the spring-loaded valve. An interesting technical point confirmed by Mr. MacNicoll is that the quantity of steam discharged through an orifice is independent of the pressure against which it is discharged, provided that this pressure does not exceed 58 per cent. of the steam pressure. Mr. MacNicoll refers to this as a theory, but I rather think it is one of those facts which are met with occasionally, and which no theory seems adequately to explain. Regarding the high-lift safety valve, I, along with the representatives of the Board of Trade and the registry societies, witnessed the more recent tests described in the paper. These conclusively prove that this valve is capable of passing the same quantity of steam as a valve of the ordinary type having twice its area. What interested me most, however, in these tests was the pressure readings in the waste-steam pipe—the rapid fall of pressure due to increase of velocity. At a short distance from the valve the pressure dropped 50 per cent., which means, I take it, that at that point the exhaust from another similar valve might have been led into the same pipe without necessitating any increase of diameter. The results appear to suggest that, if the connections were made at suitable intervals, one pipe might take the exhaust from a series of boilers without increase of diameter. It would be extremely interesting if experiments under working conditions could be arranged to ascertain if this deduction is correct, and at what intervals these connections could be made.

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Mr. J. D. Boyle.

Mr. J. D. Boyle (Member): In many of Mr. MacNicoll's designs he has used the action of the fluid on a pilot valve, which in turn operates the control mechanism of the main valve. In the high-lift valve, however, he has branched off in another direction, and the steam operates the main valve direct; later, on its passage to the atmosphere, it does additional work on an auxiliary piston.

I can confirm Mr. MacNicoll's statement that Mr. Harry Clarke took a great interest in the development of the high-lift valve. After he had witnessed the tests cited in this paper, Mr. Clarke passed the remark that just as the full-bore valve had scooped the pool in naval service, so the high-lift type was coming forward to do the same in connection with merchant shipping. The smaller the opening necessary to be cut in the boiler shell, the less weight and bulk of the castings on the boiler top, and the saving in weight of material in waste-steam pipes appear to be a few of the points in favour of the high-lift valve. Mr. MacNicoll has demonstrated that he can get at least as good results during accumulation tests with half the usual size of safety valve.

Frequent grinding of a safety-valve face on its seat without also clearing the lip tends to reduce the outer clearance to *nil*, so that the valve on blowing off does not return to its seat until the pressure has fallen considerably below the working pressure; 20 lbs. per square inch is not an uncommon drop in these circumstances. I should like to ask Mr. MacNicoll what he regards as the proper amount of lip clearance for a spring-loaded valve of the type shown in Fig. 16, from the consideration of efficiency of discharge and the sharp closing of the valve. Is the best clearance a certain fraction of the diameter, or can a fixed amount be used for all sizes of valve? I should also like to ask Mr. MacNicoll what type of safety valve, generally, is finding most favour in connection with the high-pressure water-tube boilers now being adopted for power

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stations, and what materials are giving most satisfaction for the valves and seats.

Mr. W. D. McLaren (Member): Mr. MacNicoll refers to the Board of Trade formulæ for determining the area of valves, and says that evaporation (or fuel consumption) and pressure should be the bases of calculation. May I state that, with oil-burning apparatus as usually constructed, neither the Board of Trade nor Mr. MacNicoll's factors will determine the conditions. The Board of Trade specify an accumulation test, which is carried through to the surveyor's satisfaction. Even though information regarding proposed consumption or evaporation is provided, what is to prevent larger orifices being placed in the burners than the largest that were stated would be used? What is to prevent the employment of higher fuel and air pressure in subsequent operation? Is it not reasonable to claim that, with such readily controlled apparatus, all the factors in the case cannot carry the significance formerly attached to them, and that the real factor is the engineer in charge?

In Fig. 18, Mr. MacNicoll shows the type of safety valve which is fitted in naval vessels. I understand that the Board of Trade are not in favour of this type of valve for merchant service, and I believe their reason for objecting to it is due to the fact that there is a relay action, and that seizure in the relay valve would cause inoperation of the main valve. I should like to know from Mr. MacNicoll if overtures have recently been made to the Board of Trade to accept this type of full-bore safety valve, or is it considered that the high-lift valve now meets the requirements of the merchant service so well, and is so positive in its action, that the full-bore type may be put aside? There is a great advantage to be gained in keeping down size of valves and weight, and I think that Mr. MacNicoll's high-lift valve goes a long way to provide engineers with some of the simplifications they are looking for

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Mr. W. D. McLaren.
in merchant work. The employment generally of smaller steam valves for all services, with the benefit of improved tightness, should be the trend in all designs, and it is regrettable that marine engineers should prove so conservative in adhering to steam speeds, etc., adopted in the long past, and still venerated by many as sacrosanct.

Mr. W. W. Marriner (Member of Council): It was one of the most fortunate days in my life when I met Mr. MacNicoll, because safety-valve trials were really disliked more than anything else. In the very early days "safety first" was not practised very much, because I have actually sat on a safety valve when going over the measured mile, in order to get a few pounds extra pressure.

I have knowledge of a safety valve which beats any that Mr. MacNicoll has ever designed. I once hired a launch in the Western Isles, and being an engineer I had a look at the boiler and its fittings. I could not see any safety valve, so I asked the old fisherman who owned the launch what had happened. "Oh," he said, "somebody stole the safety valve," and when asked what he did without it he replied, "I push in a wooden plug, and if it blows out I know I have too much pressure." My confidence in this fitting was so great that I wired to Glasgow for a safety valve from Mr. MacNicoll before I again ventured out in that launch.

Mr. L. F. Norrie (Member): Mr. MacNicoll has done much to improve the efficiency of spring-loaded valves, and no doubt his latest type represents a great improvement on what might be called the ordinary spring-loaded valve. At the same time, it is hardly correct to say, as one of the previous speakers said, that the spring-loaded valve has been adopted for the marine service because of its superior efficiency over the deadweight valve. It is really because the former is suitable for the conditions of marine service and the latter is not. As a matter

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of fact, I do not know that it can be claimed, or whether Mr. MacNicoll claims, that even the improved spring loaded valve is greater in efficiency than the deadweight valve. At all events, I know that safety valves of the combined type referred to in the paper have been made for many years, and makers endeavour to produce them approximately of equal capacity, but not of equal size. The standard fitting, for instance, would be a 2-inch dead load with a 3-inch spring load, or a 2½-inch dead load with a 4-inch spring load, and it is always taken that these two valves, widely different in size, are capable of discharging approximately the same amount of steam.

I notice in Fig. 22 that the closing pressure on the high-lift double-spring valve is given as 195 lbs. on a boiler working at 200 lbs. It is always regarded as a desirable feature in any safety valve that the closing pressure should not be much below the working pressure. Perhaps Mr. MacNicoll would state how much the closing pressure fell below the working pressure before the safety valve closed in the other trials, Figs. 26 and 27. In the course of his paper he refers to basing safety-valve area on the evaporation instead of on the intricate factors of coal consumption or heating surface. On that point I entirely agree with him. Nowadays when asked to quote for safety valves, makers are frequently told that the boiler has such and such an evaporation with 25 per cent. over load capacity. Each year it is getting more and more common to be asked to supply valves capable of dealing with a certain evaporation, which I think is the proper thing to do, and valve makers should not be concerned with the efficiency of the boilers.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Member of Council): I wish to call Mr. MacNicoll's attention to a statement he makes on page 147 of his paper, where he says that he was reminded "that I once held the view that the flow

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of steam through the waste-steam pipe was not affected until the external pressure was from 58 to 60 per cent. of the internal pressure," and it was suggested that a test might be conducted to prove this. Now I have looked through the paper for some report of such a test, and some definite statement as to whether he obtained confirmation or otherwise of his one-time belief. Perhaps he will oblige by telling us what his present position is.

As far as I can see, there is no indication in the formulæ which have been derived for the flow of gases through long pipes that there is such a critical pressure. Compare the flow through pipes with the flow through orifices. In the latter there is a very definite indication that, at somewhere between 50 and 60 per cent. of the pressure drop, something happens. The existence of a critical pressure has been proved experimentally, and is quite well known, but the theoretical expressions for the flow of gases through pipes do not give any such indication. There is, however, this to be said about it, that others as well as Mr. MacNicoll have felt some doubt about the application of theoretical principles to the flow of gases through pipes right out to the limit. In the concluding sentence in one section of an article on Hydro-Mechanics by Prof. Unwin, which appears in the Encyclopædia Britannica, although not directly speaking of the discharge from pipes, he (Prof. Unwin) concludes by saying that, probably for pipes as for orifices, there is a limit to the ratio of initial and terminal pressures for which the formulæ are applicable.

Mr. MacNicoll: Mr. Gibson's remarks are interesting, and while the trials of H.M.S's. "Cossack" and "Swift" were looked upon at the time as being most revolutionary in connection with safety valve design, the honour of broadly reducing valve area must be allowed to rest with Messrs. Lethuillier & Pinel some 12 years prior to the trials of these vessels. Their valve was approved about 30 years ago, at a

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50 per cent. reduction from the size as determined by the French rule of that period. What I realised at the time of the trials of the "Cossack" and "Swift" was that the British Board of Trade would never look kindly upon a piston rigidly attached either to the valve spindle or to the valve proper. It must be remembered that before a valve can be approved for general service all possibilities of its sticking must be entirely removed, and this makes it most difficult to design a valve which will lift more than $\frac{1}{24}$th of its diameter. There are other types of high-lift valve, particularly abroad, but I am afraid that assurance of action has been sacrificed to obtain additional lift.

Mr. Dow asks how the formula $\frac{E}{4P}$ was arrived at. On page 32, Vol. XVIII of the Institution's Transactions, Mr. Brownlee says that "the weight in pounds of steam discharged per minute per square inch of opening with square-edged entrance corresponds very nearly with three-fourths of the absolute pressure in the boiler, as long as that pressure is not less than 25·37 lbs." Further, on page 33, he states that "in ordinary marine practice there is not often more than 20 lbs. of coal consumed per hour per square foot of fire grate (this, of course, is natural draught), and the water evaporated seldom exceeds 9 lbs. per lb. of coal, which corresponds to 180 lbs. per hour. . . . Under those conditions, the area of opening requisite to discharge all the steam a boiler can generate corresponds to four times the square feet of fire grate divided by the absolute pressure," or $\frac{4G}{P}$.

This, I think, determines the basis for safety valve area to be evaporation and pressure. To illustrate this, assume 100 square feet of grate area and 100 lbs. absolute pressure. Then using the formula $\frac{4G}{P}$, a valve area of 4 square inches is obtained. The evaporation per hour is 18,000 lbs. of steam, and the

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Mr. Donald MacNicoll.

quantity discharged per hour per square inch of orifice is 4,500 lbs. Dividing 18,000 lbs. by 4,500, the result is 4 square inches. Consequently the formula is $\frac{E}{45P}$, E being evaporation and P absolute pressure. Except that a frictional factor must be introduced, the formula would be quite in order for valves that lift $\frac{1}{4}$th of their diameter, but as the Safety Valve Committee suggested that ordinary valves only lifted $\frac{1}{36}$th of their diameter, so that the disc area of the valve was nine times the actual area of escape, the factor 4 was changed to 36, and when the formula emerged after consideration by the Board of Trade the factor had become 37·5.

Now the formula $\frac{37{\cdot}5 \times G}{P}$ is actually equal to $\frac{E}{4{\cdot}8P}$, on the basis of 20 lbs. of coal consumed per square foot of grate and 9 lbs. of water evaporated per lb. of coal. From numerous accumulation trials, it appeared to me that the Board of Trade formulæ gave a rather small valve area. Consequently I changed 4·8 to 4, which gives $\frac{E}{4P}$.

Mr. Baird remarks that he has experienced a greater fuel consumption than 25 lbs. per square foot of grate. This supports my contention in connection with the omission of a fuel value in the formulæ. What I would like to emphasise is this, that while rules lay down a minimum size of valve, it is generally understood that the accumulation of pressure must not exceed a certain amount. As stated in the paper, the new rule does not take fuel consumption into account, and, therefore, it has occasionally been found necessary to provide a valve of greater capacity than one given by that rule. A suitable valve for any conditions may be obtained by using the formula $\frac{E}{4P}$.

Mr. Barr's suggestion in connection with the main waste-steam pipes is interesting, and undoubtedly deserves consideration in view of the keen competition to-day.

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Mr. Boyle raises a most interesting point regarding pressure drop. A safety valve is only operated by a slight range of pressure, and the pressure drop should be between 3 and 5 per cent. of the popping pressure. The opening between the top edge of the cup on the seat and the underside of the plate on the valve should be $\frac{1}{4}$th inch, and the breadth of the face of the valve and seat $\frac{1}{16}$th for all sizes of valve. Should the valve be ground in, and the opening made less than $\frac{1}{4}$th inch, the drop will increase as Mr. Boyle suggests. An even worse feature is the broadening of the valve and seat faces, which permits the valve to fizzle and leak at considerably below the working pressure; this at least wastes a great deal of steam. Shipowners and their representatives should arrange with the registry societies for popping of the safety valves to take place at about 5 per cent. above the working pressure. This would reduce the cost of valve maintenance and save fuel.

With regard to valves for high pressures, I may say that for the past three years I have been engaged on the design and construction of fittings for pressures of from 300 to 800 lbs. per square inch, and have come to the conclusion that cast steel must be used for the valve chests. Up to temperatures of 750 degrees F., nickel bronze alloy mountings can be used, but for higher temperatures stainless steel is essential. The scoring action of the steam is an acute problem, and it has been found that for a pressure of 800 lbs. it is necessary to adopt full-bore valves with screened faces, with the actual area of discharge much less than the area at the valve faces, so as to reduce the steam velocity over the faces as much as possible.

Mr. McLaren makes a somewhat sweeping statement when he says, "May I state that, with oil-burning apparatus as usually constructed, neither the Board of Trade nor Mr. MacNicoll's factors will determine the conditions." The Board of Trade merely subscribed to the factors or formulæ, which certainly give a hard and fast rule for the size of valves for

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Mr. Donald MacNicoll.

both coal and oil, and, as I have already stated, do not take fuel consumption into account. On the other hand, while my formula does not determine the conditions, it provides particulars from which the size of valve may be determined for the maximum evaporation. Given the maximum capacity of oil-fuel pumps, and allowing an evaporation of 12 lbs. of water per lb. of oil under accumulation conditions, Mr. McLaren can obtain a suitable size of valve from $\frac{E}{4P}$. I think he has a concrete case in his mind when he speaks in this strain. Might I suggest that it was particularly the want of a fuel factor in the formulæ that caused the trouble, as I know it has on a number of occasions.

I consider the relay valve most reliable as far as absolute safety is concerned. My reason for not advocating this type for mercantile work is, briefly, one of cost. Except in boilers evaporating approximately 25,000 lbs. of steam per hour at 200 lbs. pressure, ordinary valves in cast iron are much cheaper. In naval work where gun-metal or cast steel is used the position is different, and in addition the question of weight is of vital importance.

Might I say, in reply to Mr. Norrie, that during all the tests referred to in the paper the pressures at which the valves shut down ranged from 5 to 7 lbs. below the popping pressure. Mr. Norrie suggests that a deadweight valve is more efficient than a spring-loaded one. On this point I agree with him, as will be seen from my remarks on pages 114 and 115, but once either a direct deadweight valve or a spring-loaded valve is made to lift $\frac{1}{4}$th of its diameter, there is very little to choose between the forms of loading. Mr. Norrie cites the case of specifications for 2-inch deadweight valves and 3-inch spring-loaded valves, and suggests that the steam discharge from a 3-inch spring-loaded valve is the same as that from a 2-inch deadweight valve. The area of the 3-inch valve is approximately double that of the 2-inch valve, so it appears that a

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Mr. Donald MacNicoll.

2-inch high-lift spring-loaded valve would be a most suitable fitting to work in conjunction with a 2-inch deadweight valve. I am glad that Mr. Norrie agrees that safety-valve area should be designed for evaporation.

Mr. Riddlesworth refers to my statement on page 147, but I would ask him to take it in conjunction with the next paragraph, and from the two he will be able to deduce the confirmation he desires. It occurs to me that he is looking at my statement—"that the flow of steam through the waste-steam pipe was not affected until the external pressure was from 58 to 60 per cent. of the internal pressure"—from quite a different angle to what I intended. It appears that he is considering the case of a safety valve with its waste-steam pipe blowing off, and having, say, a pressure at the base of the pipe of one per cent. of the boiler pressure. The boiler is then forced until 58 per cent. of the boiler pressure is reached at the base of the waste-steam pipe. Obviously the flow through both the valve and the pipe has been increasing all the time, but this is not similar to the conditions which prevailed during the tests I carried out. Briefly, the position is this. It is known that the flow of steam through an orifice does not change until the external pressure exceeds from 58 to 60 per cent. of the internal pressure. Assume that an accumulation trial has been run and that the pressure at the base of the waste-steam pipe is found to be one per cent. of the boiler pressure, and the trial repeated, but with a stop valve inserted between the safety-valve outlet and the waste-steam pipe. Then if the stop valve at the commencement of the second trial was screwed down until the pressure in the waste-steam portion of the chest, which constitutes the base of the waste-steam pipe, reached 58 per cent. of the boiler pressure, the evaporation and the size of waste-steam pipe being equal in the two cases, it of necessity follows that the flow in the waste-steam pipe was the same in the two cases. In the first case, the valve discharged into a pressure of one

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per cent. of the boiler pressure at the base of the waste-steam pipe, and in the second it discharged into a pressure of 58 per cent. in the chamber between the stop valve and the safety valves. This is what I intended to convey.

I would like to add that the trials in connection with the improved high-lift safety valve must not be looked upon as experiments on steam-flow through orifices and pipes. Experiments of this nature would call for condensing and measuring apparatus, and also fixed orifices and not variable ones, as in the case of a safety valve.

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POSSIBLE FUTURE DEVELOPMENTS IN ATLANTIC EXPRESS PASSENGER SERVICES.

By JOHN ANDERSON,
Member of the Institution.

17th November, 1925.

It might truthfully be said that since the beginning of the steamship era most of the innovations in ship design and marine engineering owe their advancement, in a large degree, to the competition which has prevailed between different owners for supremacy in the Atlantic passenger trade.

A study of Sir George Holmes' work, "Ancient and Modern Ships," shows the various steps which have been taken in attaining the present position. There it is seen that after the successful crossing by the wooden paddle ship "Savannah" of 350 tons in 29½ days in 1819, and, nine years later, by the "Great Western" of 1,321 tons in 17 days (the latter on a total coal consumption of 520 tons), the system of hull construction was discarded in favour of iron in the "Great Britain," by which means the weight of hull was reduced by one-third; incidentally, this ship was also the first screw-propelled vessel to make the crossing. In 1862 compound engines were adopted by the Pacific Navigation Co., and this development is said to have reduced the fuel consumption by 50 per cent. Ten years later steel was adopted for merchant ships in the "Buenos Ayrean," and yielded a reduction in hull weight of 15 per cent., and when triple-expansion engines were installed in the "Aller" of 18 knots, the coal consumption was reduced by a further 30 per cent. In 1890 twin screws, driven by triple-expansion engines, were adopted for

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the "City of Paris," and it is on record that after the shaft bossings of that vessel were altered the desired speed was attained with a reduction of 2,000 h.p. Each of the steps named was accompanied by a considerable increase in speed and in the dimensions of the hull, and, in 1892, all past records were eclipsed by the construction of the famous liner "Campania," a vessel of 600 feet in length and a speed of $21\frac{3}{4}$ knots, the 28,000 i.h.p. being developed by two five-cylinder triple-expansion engines. That achievement stood foremost for six years, until the North German Lloyd launched forth with the "Kaiser Wilhelm der Grosse" of $22\frac{3}{4}$ knots, a vessel outstanding on account of the magnificence of her accommodation, and her all-round supremacy was not lowered until eight years later, when the Cunard Co., with the assistance of the British Government, built the "Lusitania" and "Mauretania."

The characteristics of these famous vessels are well known to the present generation, and it is sufficient to state that the latter vessel has a length of 760 feet, was designed for a service speed of 25 knots with coal fuel, but since being adapted for oil burning has attained fully 26 knots. This ship has four lines of shafting, each driven by direct steam-turbines, and part of the topside structure is of high-tensile steel.

Since the developments introduced by the "Mauretania" a number of larger vessels have been built, of which the latest example is the "Majestic," which is 915 feet in length. These recent vessels have all been luxuriously fitted out, but it is understood that none of them has attained as high a speed as the "Mauretania."

It is worthy of note that on three occasions desire has been shown to reduce speed in first-class liners. It is stated that just prior to the introduction of the epoch-making Guion liners in 1875, one company built three ships of intermediate speed, but on account of the threatened competition they were never

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used on the Atlantic service. During the severe trade depression in 1892 a number of vessels of about 16 knots were built, and again after the great war (when costs were at their highest) the majority of the North Atlantic passenger ships were designed for speeds of from 15 to 16 knots.

The foregoing allusions are principally to the advancements due to material, machinery, and fuel consumption. Up to the year 1860 the typical Atlantic liner was a vessel with poop and forecastle connected by bulwarks about 7 feet high, having only scuppers to clear them of water; but as speed was increased the danger to passengers became evident, and the spar-deck type was introduced, which meant that the weather deck was raised about 7 feet 6 inches higher. Since then the principle of increased top hamper has steadily advanced, with an accompanying increase of weight, which is a factor operating against any desire there may be to increase speed or radius of action. The growing demand of the travelling public for more luxurious accommodation, and the recent legislation introduced with the object of ensuring greater safety of life at sea, have also considerably increased the weights of vessels.

It should be stated that none of the improvements effected appears to have been accepted spontaneously. In 1787, when John Fitch attempted to borrow £50 to enable him to complete his steamboat, none of his friends would advance the money because they believed him to be crazy. French naval architects adopted the use of iron for hulls some years before we did, the retarders at that time being our postal authorities, who are said to have had doubts regarding the floatability of such craft. Although the screw propeller was successfully used in the "Great Britain," paddle engines were almost invariably adopted until the impracticability of the large wheels was proved under heavy weather conditions. The Cunard liner "Scotia," built in 1862, was the last transatlantic vessel of that type, the paddles being 40 feet in diameter for a speed of 13½ knots.

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It is now 18 years since the last breakers of speed records were completed, and since then many improvements in hull and machinery have been effected, and, in addition, our knowledge of resistance and propulsion has been considerably advanced.

Oil is now available as a fuel, and permits of a reduction in fuel weight of 30 per cent. compared with coal, and can be stored in remote parts of a vessel, thus dispensing with the many inconveniences associated with coal. Oil fuel also simplifies (so far as the topsides are concerned) the design arrangements, and it can be put aboard in much less time than coal, incidentally reducing the time required in port.

The use of gearing for obtaining a correct balance between the efficiency of propellers and turbines has now been put on a practical basis, and has resulted in a reduction in fuel consumption of about 15 per cent. as compared with triple-expansion engines.

The advantages accruing from superheating are also well known.

The efficiency of turbine machinery is being advanced considerably further by following the land practice of generating steam at 500 lbs. pressure per square inch in water-tube boilers, and by regenerative heating of the feed-water. By these means the weight of a machinery installation may be reduced by 25 per cent., and the fuel consumption by 20 per cent.; the reduced amount of space required in large vessels for such installations will permit of more space being available for passenger accommodation.

The structural design of the hull of large vessels has been considerably advanced; those vessels with high freeboard ratios now receive much more favourable treatment, and new materials for covering decks and other matters of outfit have induced economies in weight to the extent of about 10 per cent.

Considerable application has also been given to improving

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the elastic strength of structural steel, and the material now available permits of a further reduction in weight of hull of about 10 per cent.

The question which it is desired to discuss is: "*Will such improvements be utilised in further reducing the time to cross the Atlantic, or have new competitive factors arisen which will effectively displace waterborne transportation?*"

Great efforts are being made to develop long distance air services, and both airships and heavier than air machines have crossed the Atlantic. Will they be advanced sufficiently to meet the demands for fast travelling, and can the cost of that means of transportation and other inducements be made sufficiently attractive to cause travellers to forsake the greater comforts associated with waterborne vessels?

At the British Association meeting in Southampton this year, Mr. Oliver Simmonds stated that he would consider progress inordinately slow if, within the next decade, we had not constructed a flying boat of 100,000 lbs. gross weight, capable of carrying about 100 passengers at a speed of 100 miles per hour, and that such a vessel would fly from Europe to America with only one stop at the Azores, and accomplish this flight within 36 hours.

On the other hand, can and will the speed of waterborne vessels be increased sufficiently to meet such competition? And will the travelling public regard such aerial flights as scientific achievements but as being unsuitable for commercial purposes?

Proposals have already been made to increase the present speeds of waterborne merchant ships, for it is common knowledge that at one time the American Shipping Board contemplated building vessels 1,000 feet long and with a speed of 30 knots.

During a recent conversation with an authority on the Atlantic passenger trade, he predicted that a day is coming when waterborne liners will be running across the Atlantic

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at a speed of 40 knots, which means that instead of the journey between Cherbourg and New York occupying a minimum of five days as at present, the time would be reduced to three-and-a-quarter days. It may be stated that it was this conversation which prompted me to prepare these notes. It is apparent that, even with all the advances named, a speed of 40 knots could not be obtained with our present knowledge if orthodox practice in design is followed, but it is of interest to examine what could be done in design by developing such practice, and also by alternative methods which have been suggested.

In 1924 Sir Eustace Tennyson-d'Eyncourt placed proposals before the Institution of Naval Architects for a waterborne vessel of 22 knots speed which was to be specially assisted by aeroplanes. The main idea in this case was that passengers starting from some distance on each side of the terminal ports could leave or arrive by aeroplane some considerable time after or before the vessel sailed or arrived in port, and in this way save the losses due to land travelling, manœuvring, and embarkation. No doubt some saving in time could be effected by this arrangement, but it is open to doubt whether it would be suitable for most of the travelling public, and also if the landing of aeroplanes on the deck of a vessel on the Atlantic would be popular with passengers.

In his address to the British Association at Liverpool in 1923, Mr. A. T. Wall predicted a day when passengers might cross the Atlantic in skimming vessels, but no details of any developed system were suggested. It is proposed to examine this suggestion, and compare it with the results obtained by extension of design on orthodox lines.

Although so much experience has now been gained in the design of Atlantic liners, many presumptions must be made to meet the new conditions which have developed, amongst which are:—Maximum length of vessel, limiting draught, docking facilities, block coefficient, necessary freeboard, structural pro-

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portions, maximum desirable metacentric height, maximum power and the method of transmitting it, efficient lifetime of such vessels, etc., and it seems desirable to discuss these factors briefly.

Length. The upper limit of length for a fixed speed will yield the best ratios of volume available for passengers, and the opposing factor is the difficulty of handling very large vessels; difficulties in this direction have already been mentioned in connection with existing vessels, but as lengths of 965 and 1,000 feet have been named by certain authorities, the latter might be used for the present purpose.

Draught. As the operations of deepening channels would be dependent upon the amount of traffic, it is thought that no action would be taken for special cases, and it is, therefore, desirable to assume a draught not greater than that of the "Mauretania," namely, 36 feet 3 inches.

Block Coefficient. In earlier record-breakers this was about ·6. Presumably this standard was chosen as a minimum for sea-going conditions, but it is known that a finer model of, say, ·52 would result in a reduction in power of about 18 per cent. It is suggested that the finer model with a specially full above-water form would meet the requirements of service, and result in a reduction in power of, say, 10 per cent.

Freeboard is very important for high-speed vessels in heavy weather, and the possible results from such proposals should demand a height from the waterline to the forecastle head of at least 50 feet.

Structural Proportions. The present arrangement of mid-ship superstructures has been induced to a considerable extent by structural considerations, in addition to giving more comfortable housing for passengers, and also by the desire to obtain suitable positions for navigation. Considering, however, the high ratio of structural freeboard to draught in very large vessels, and the consequent reduction in stresses, it is thought possible to adopt a length to depth ratio to the top structural

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member of 15. Adequate stiffness might be obtained by means of lattice girders or some other similar method. It is important that partial superstructures should be at a minimum in high-speed vessels on account of wind resistance.

Docking Facilities. Reference to Mr. A. C. F. Henderson's paper, read before the Institution of Naval Architects in 1923, shows that new facilities would require to be provided in the event of any development.

Metacentric Height. Mr. Henderson's remarks of 1923 appear to indicate that the GM may be fairly widely increased beyond previously accepted limits without inducing undue discomfort.

Maximum Power and Transmission of Same. It is thought that four shafts are the maximum number which could be conveniently provided for.

Sir Eustace Tennyson-d'Eyncourt stated, in 1920, that the 36,500 s.h.p. per shaft on trial obtained on H.M.S. "Hood" was the highest on record, and so far as is known that amount has not been exceeded. For continuous service conditions it is improbable that more than 80 per cent. could be maintained, or, say, 30,000 s.h.p. However, it is possible that many improvements may have been effected since then, although it is understood that some limit would be fixed by mechanical considerations. It is, therefore, presumed that the service power per shaft would not exceed 40,000 s.h.p.

Efficient Lifetime. The design of both hull and machinery, so far as weight is concerned, is considerably influenced by what might be considered the efficient lifetime of the vessel, namely, in the allowance for corrosion in the former and for wear and tear for both, and, considering how rapidly design advances to-day, it is questionable whether a vessel of this type would not become obsolete in, say, 20 years or less.

Grouping together all the considerations named, in order to arrive at a vessel of the orthodox type, the following is obtainable for a voyage of 3,100 nautical miles:—

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Dimensions	1,000 feet × 102 feet × 67 feet.
Draught	36 feet 3 inches.
Block coefficient	·52
S.H.P.	160,000
Weight of hull	30,000 tons.
,, ,, machinery	13,000 ,,
,, ,, fuel for four days with the necessary margin	5,500 ,,
,, ,, fresh- and feed-water for ditto	2,500 ,,
,, ,, baggage, ,, ,, stores, ,, ,, cargo (mails, etc.)	3,000 ,,
	54,000 ,,

The corresponding service speed for the above would, in all probability, not exceed 32 knots, which would enable the passage to be made in four days, and this may be taken to represent roughly the best that can be done, on orthodox lines, with our present knowledge. The accommodation in such a vessel would be for about 3,500 to 4,000 first, second, and third class passengers.

Although the speed indicated is far below that named by the authority already referred to, it is so much higher than that for any existing mercantile vessel as to suggest the necessity for a reconstruction of ideas.

Open promenades on such a vessel would, for instance, be untenable on account of the discomfort due to speed, and airing space would require to be screened. If this view were accepted, it would be desirable to rearrange the structural height of the main hull so that all airing spaces might be contained in it, and this in turn would be a help to the structure. The suggestion here is a flush-deck vessel with all

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accommodation and airing spaces contained below deck, and only the life-saving appliances and ship's equipment above.

This at once raises the question of necessary height for navigation purposes, but it is thought that, with all the present appliances for navigation, it may be unnecessary to have a large navigating bridge at a great height above deck. Would it not be possible and desirable to direct navigation from a tower or nest on the foremast, with communicating stations at the extremities of the vessel?

Consider now the potentialities of Mr. Wall's vision. The expression "skimming" conveys the impression of a vessel with small displacement, only lightly touching the water, and travelling at a high speed; for the present purposes this speed might be assumed to be the 40 knots already suggested. If such a craft were intended to maintain continuous service, it would require to be constructed of sufficient strength to withstand the heavy weather regularly encountered on the Atlantic, but very lightly constructed in order to obtain a very low displacement-length ratio.

If the hull were specially constructed and built of steel having an elastic limit of 20 tons per square inch, and if efficient machinery could be obtained to yield 100 h.p. per ton weight and consume not more than ·4 lb. of fuel per horse-power per hour, the following might result for a speed of 40 knots:—

Dimensions	500 feet × 50 feet × 30 feet.
Draught	10 feet 9 inches.
Block coefficient	·6
S.H.P.	100,000
Weight of hull	2,000 tons.
,, ,, machinery	1,000 ,,
,, ,, fuel	1,400 ,,
,, ,, water, stores, passengers, etc.	200 ,,
	4,600 ,,

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It will be seen that the foregoing represents a vessel much lighter than any existing high-speed craft which has been built for ocean service, and, of course, its lifetime would be very short. In addition it would not accommodate more than 150 passengers, and it is very doubtful whether it could be fully used except in moderate weather.

I conclude from this outline survey that the immediate future developments will be along orthodox lines, *i.e.*, large vessels stoutly built and luxuriously furnished, and am of opinion that if the average passenger has to choose between high speed with discomfort and a lower speed with great comfort, the last consideration will be found to be the dominant factor except in cases of extreme urgency.

Discussion.

Mr. MAURICE E. DENNY, C.B.E., B.Sc. (Vice-President): I wish, at least up to a point, to comment rather discursively on this paper, which Mr. Anderson must have enjoyed writing. We find him in a Wellsian mood, and I almost expected him to advise us that his skimmer would be commanded by a Martian. He mentions high-tension steel in connection with the topsides of the "Mauretania," but elsewhere in his paper he remarks that material is now available which permits of a further reduction in weight of hull of about 10 per cent., on account of what he calls the improved elastic strength of structural steel. A great deal has been said recently about new steels, and I am prompted by a sense of humility to avow at once that I really do not quite know where we stand. For instance, when Mr. Anderson refers to high elastic strength, I am not sure that I understand what he means. We are told that one steel is stronger than another; but I am quite certain I do not know what that means. However, that brings me to the point of suggesting to the Secretary that members of this Institution would welcome

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Mr. Maurice E. Denny, C.B.E., B.Sc.

and would profit very much indeed by a paper, bringing our knowledge up to date, on the properties of steel. We have members who are competent to prepare such a paper, and it is possible that steel makers know a good deal more than they have already told us.

Mr. Anderson mentions a steam pressure of 500 lbs. per square inch as a modern advance in propelling machinery. I am giving away no secret in reminding you that a vessel is now being built for passenger service having a boiler pressure somewhat in excess of that figure. More will be known about this new departure after her trials, which will probably take place in May.

Referring to the table on page 177, it will be seen that more than 10 per cent. of the displacement of the fast ship is taken up by fuel. Now, if a reduction could be made in this of 25 or 30 per cent., as Mr. Anderson suggests, there would be a most substantial saving in power. I have sketched out, very roughly, a vessel to approach a speed of 40 knots of the type suggested by Mr. Anderson, and am of the opinion that, even without being unorthodox, such a vessel, if compelled to carry fuel only for a few hours' run, could be built on a length of about 500 feet. Mr. Anderson apologised for not mentioning the advantages of the cruiser stern. Perhaps he was wise in omitting reference to that feature. Many will agree that the cruiser stern does, or can be made to, reduce the resistance, and therefore the e.h.p. of a ship, but whether it always reduces the s.h.p. is another question. It is at least open to doubt in some cases.

Mr. Anderson finishes with his skimmer. The literature on the subject of skimmers is somewhat scanty, but I have looked up some figures, and admit at once that a designer must have considerable faith in the law of comparison to bring a 40-foot boat up to one of 500 feet or more. It seems possible, however, that a 500-foot vessel, with a suitable beam, would begin to skim at somewhere about 50 or 60 knots. Now Mr. Wall's

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Mr. Maurice E. Denny, C.B.E., B.Sc.

or Mr. Anderson's vessel, which has a length of 500 feet, was to have a speed of 40 knots, with a horse-power of the order of 100,000, but I suggest that it is an error of nomenclature to call her a skimmer, because at that speed she would not begin to skim—she would remain a full displacement vessel. If a 500-foot boat could be made to skim, the speed would then rapidly increase possibly to about 110 knots, the power only going up roughly as the speed, but reaching large figures. Even the most prophetic will hesitate to predict that 400,000 s.h.p. will be put into any floating object to be a success commercially.

Finally, I wish to thank Mr. Anderson for giving us this opportunity to exercise our imagination, and I most cordially agree with him that the day is far distant when the Atlantic will be crossed in something approaching the skimmer. All who have crossed the Atlantic in dirty weather and been on the Newfoundland banks in November, can scarcely vision a vessel bounding from crest to crest with the passengers inside enjoying any degree of comfort.

Mr. J. L. Adam (Member of Council): As this paper is largely an effort of imagination, and I have always been told not to let my imagination carry me away when dealing with technical subjects, I find it rather difficult to discuss. The portion, however, that interests me particularly is that in which Mr. Anderson deals with structural development. His remarks regarding top hamper are particularly apposite in view of present-day developments. I agree with him that, structurally, superstructures as originally designed were top hamper, and I think that the British Corporation Registry may claim credit in that they strongly advocated the embodiment of the upper works in the structural design of vessels, the consequence being that to-day, in the latest liners of 600 feet and over, the whole of the structure, with the exception of the boat platform, is included in the hull girder. This results in pro-

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Mr. J. L. Adam.

portions of less than ten, not 15 depths to length as Mr. Anderson indicates, and I am informed that by so utilising the depth something like from 400 to 500 tons can be saved on the weight of a ship of this size as compared with the old style of vessel in which the superstructures were not an integral portion of the structure. It is, I think, doubtful if the structure of the 1,000-foot vessel specified by Mr. Anderson could be made efficient on a depth of 67 feet and yet obtain that necessary saving in weight which is known might be obtained with a greater depth of girder.

It is possible that in a vessel of the length and breadth indicated by Mr. Anderson such a depth as 100 feet could not be wholly utilised, although it would give proportions of depth to length, depth to breadth and draught, practically identical with those in in some vessels already in service, and if fully utilised would result in increased comfort of the passengers by higher 'tween decks and larger enclosed promenade spaces. Even with present-day speeds it is, I understand, generally accepted that for Atlantic service the promenade deck spaces should be enclosed.

To the saving of the steel weight gained by such proportions, it may be possible to add something by the use of improved material. Mr. Anderson, as is generally known, has had unique opportunities of obtaining practical experience on which to base his remarks on the subject of possible savings from this source. I do not know whether a correct specification for such improved material as he indicates would be a 20 tons elastic limit, as nobody seems to know what elastic limit really is; but I think it can be accepted that, even after due provision is made to resist compression forces and due account is taken of corrosion, it is justifiable to count on a reduction in the steel weight by using improved mild steel, which, at any rate, may be relied on to resist alternating stresses more effectively, and it is hoped that the interesting experiment in which the British Corporation Registry has had

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Mr. J. L. Adam.

the pleasure of being associated with his firm will go far to prove this.

The vision of Atlantic skimmers is interesting. Some years ago I had some personal experience of skimmers and hydroplanes, and to my mind it would be exceedingly interesting to see a 500-foot skimmer making a North Atlantic passage in winter at the speeds indicated by Mr. Anderson. From the complaints made by passengers in ordinary vessels when they suffer the results of slamming in a sea-way, it is just possible that the clientele for such vessels as Mr. Anderson suggests might be rather limited.

Mr. S. B. Ralston (Member): I find it difficult to say very much about this paper, as I do not quite know how to take it. Either Mr. Anderson is a prophet of considerable eminence or an accomplished romancer. But I must thank Mr. Denny for giving a probable solution by comparing Mr. Anderson to the novelist, H. G. Wells. Mr. Anderson deals with the advances in shipbuilding and engineering in terms of percentages, which I am inclined to think is a dangerous method. His survey of past history shows very large percentage improvements in fuel economy and weights of hull and engines, but those spacious days cannot now be repeated, and I question whether the economies that Mr. Anderson suggests can be realised.

However, on the basis of a lighter hull, lighter and more powerful engines, and greater economy in fuel than has yet been realised, Mr. Anderson arrives at an Atlantic liner of 1,000 feet length and 32 knots speed, a modest speed compared with the 40 knots predicted by the unnamed authority quoted in the paper. I am unable to see how such a vessel could carry a deadweight in any way approaching that necessary for the voyage across the Atlantic; but the paper is an inspiring one, and should lead to a very interesting discussion.

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Capt. S. R. Aitken.

Capt. S. R. AITKEN (Member of Council): It is frequently imagined that passengers are all in a tremendous hurry to cross the Atlantic, but I am not quite sure if that is altogether the case. The need of increasing speed in aerial or railway travelling owing to the general discomfort attached to these methods of transportation can be readily understood, but ship-owners have studied their passengers to such an extent that travelling on board ship is just as comfortable as living in a first-class hotel. Possibly the great desire of a passenger to get quickly across the Western Ocean is due to the fear of sea-sickness. While speeding up would shorten the passage, I doubt very much if it would in any way minimise the liability to sea-sickness. In a number of cases speed may be of importance, but, generally speaking, people are travelling for pleasure, and comfort is the first consideration. A 25-knot ship makes the west-bound passage in about 5 days 4 hours steaming time. Allowing for the difference of time between Great Britain and New York, a saving of 5 hours is made, giving a nett passage of 4 days 23 hours. If the ship sails from Southampton at noon, she should arrive at New York at 11 a.m. on the fifth day; if her speed is 26 knots, she would effect a saving of 5 hours, arriving at 6 a.m. No distinct advantage would be derived by arriving any earlier and disturbing passengers for quarantine and Customs purposes. To arrive at 6 p.m. the previous evening would mean an increase in speed to about 29 knots. This would necessitate passing quarantine and the Customs officials after dark, which is not a very satisfactory arrangement. It is, therefore, obvious that a speed of 30 to 32 knots would be required in order to arrive, pass quarantine, and land the passengers before dark. It is hardly possible to advance the time of sailing from this end, as most of the passengers travel to Southampton by the morning train. Slightly different conditions obtain in travelling east, as the 5 hours have to be added. A 25-knot ship would make 5 days 9 hours actual steaming, and the 30-knot ship would take

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4½ days, landing the ship at Southampton at midnight. It would appear that the 26-knot ship would be most serviceable for both passages, giving 4 days 23 hours west-bound and 5 days 4 hours east-bound, each way giving a daylight arrival, particularly if the ship left New York at daylight. Comfort plays no small part in the popularity of a liner, and a number of comparatively slow vessels are a good deal sought after. To increase the speed much over 26 knots would probably mean discomfort in heavy weather.

If, as Mr. Simmonds says, there is a possibility of flying boats making the trip in 36 hours and carrying 100 passengers, it would appear useless for the steamship to try to compete against this. The skimming ship does not appear to me a practical proposition in the North Atlantic trade. The draught given may be taken as the mean draught, say of 5 feet forward and 15 feet aft. The latter would be required for immersion of the propeller. A ship in such a trim would not face a westerly gale, but would probably fall off into the trough of the sea. The question of pounding would be a very likely one, and, therefore, no comfort could be expected.

On the question of the height for navigating purposes, in a trade where fog is prevalent the lower the bridge the better, as objects are better picked up in fog from a low position. It might be possible to have the bridge well forward, but the master's accommodation should be close to the bridge. It is necessary to have the navigating compass on the bridge, and the proposed position on the foremast might lead to complications from the adjuster's standpoint, and interfere with the clear view which is required round the compass.

Mr. W. W. Marriner (Member of Council): I thought it might interest the members to hear what one of their honorary members, Sir Alfred Yarrow, said, when he landed from his annual voyage this spring, on the direction in which trans-atlantic travel will probably develop. His remarks were:—

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Mr. W. W. Marriner.

"I venture to think that, although the days of the prophets are over, there can be little doubt that in 20 years' time, and possibly sooner, communication across the Atlantic, by those who are exceptionally limited for time, will be by air. The effect of this development on the design of vessels for crossing the ocean will be that excessive speeds now demanded will no longer be required. In all probability vessels of the size of the 'Mauretania,' with a speed of from 19 to 20 knots, propelled either by internal-combustion engines or turbines combined with water-tube boilers, will be adequate to secure what is needed. Vessels of this size and of half the power of the 'Mauretania' could be run with economy, and the great saving in weight in the engines, boilers, and fuel would secure a largely increased cargo-carrying capacity, and, if desired, more cabin accommodation."

The Yarrow firm have had some experience with skimming boats, and in one of the latest destroyers it was suggested that they might be approaching a speed at which skimming would take place, and thereby reach speeds which vary more nearly proportional to the horse-power developed instead of speeds which, as at present attained, vary as the cube of the power. A good many experiments tried at the National Physical Laboratory showed the impossibility of a vessel of the shape of a destroyer skimming under any circumstances. For skimming, beam is required, not length. Planes were fixed on the model of a destroyer so as to get some of the advantage of skimming, that is to say, to carry some of the one thousand tons on planes at a lower resistance, and carry the rest of it in the ordinary way; but in order to get any possible gain, double the horse-power would be required from the same weight of machinery, and at the same time a reduction in weight of hull by one-half. Another difficulty in skimming is that it does not begin until quite a respectable speed is reached, and in some skimming boats which we built, the power required to arrive at the skimming speed was much greater

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than the power required when once the vessel had got on top of the water. Another point is that a skimming boat depends upon the angle with which it meets the water, and that angle, a very small one, lies within very small limits. At an angle of about five degrees a boat might skim, whereas at an angle of about 15 degrees she would not skim. If by any chance the vessel happens to get level with the water when going at a high skimming speed, the probability is that she would dive. I have been on a skimming boat travelling at 50 miles an hour on the Firth of Clyde, and she happened to get into the wash of a very large vessel. She went over the first wave, and those on board got a fright, and unfortunately did the wrong thing when the next wave came. She was slowed down, and in doing so the boat's nose dropped sufficiently, when going down the wave, to get level with the water. Consequently, on meeting the upward slope of the next wave, she went completely under the water, which made those on board think that if they were skimming in any vessel of the size of a destroyer it would be uncomfortable.

Mr. T. R. Thomas, B.Sc. (Member): Mr. Anderson raises a question of the use of "elastic limit" steel with a view to reducing the hull weight. He suggests that he might use steel having an elastic limit of 20 tons per square inch, in place of the ordinary mild steel used at the present day. I suppose that he intends to reduce the inertia of the midship section of the vessel somewhere in the region of from 10 to 20. In other words, he proposes to half the inertia of the section. If he does so, he will immediately double the deflections to which that ship and every portion of her is liable, provided, of course, that the modulus of the material is not increased. This is, I consider, a dangerous proposition, and one which I have no doubt would lead to considerable trouble if it were tried. I should like to suggest that the steel-makers and those interested in the production of a better steel are con-

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Mr. T. R. Thomas, B.Sc.

centrating rather much on this question of elastic limit. From the shipbuilders' point of view, it would be productive of better results if steps were taken to obtain a material having a higher modulus of elasticity rather than a higher elastic limit.

This is one aspect of Mr. Anderson's paper, and, as I see it, the paper is divided quite distinctly into two separate portions. Mr. Anderson throws out highly imaginative suggestions concerning the design of his ship, in addition to raising some rather startling technical questions. I do not quite see why Mr. Anderson has to go to 1,000 feet in length and to carry from 3,500 to 4,000 passengers. He is apparently in competition with an air machine whose passenger capacity does not exceed, he suggests, more than 100 passengers. The cost of travelling by such a machine must necessarily be high, while the comfort attained is comparatively low. Therefore, the competition which he has to face is not, I consider, properly met by the design of a ship to carry from 3,500 to 4,000 passengers, but one which will carry, and with no great luxury, say, 100 passengers at a fairly high cost. Now, can this not be done on a length of less than 1,000 feet? Mr. Denny rather hinted that it might, and that he, or his firm, had been responsible for ships having a very high speed-length ratio of a length much less than 1,000 feet. I suggest to Mr. Anderson that it is possible to evolve a ship on the lines of a destroyer in which accommodation might be provided for a small number of passengers willing to pay a big price for increased speed of travel, combined with an element of safety which cannot be obtained by air.

In his paper Mr. Anderson has broken entirely fresh ground, and he is to be congratulated on doing so. I do not think any invention has ever been made without imagination. Imagination has been an important attribute of the people who have made big advances in science and art, and unless our imagination is stimulated it is hardly possible to make the same advances as our predecessors.

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Mr. W. H. Riddlesworth, M.Sc., M.Eng.

Mr. W. H. RIDDLESWORTH, M.Sc., M.Eng. (Member of Council): I have been very much struck by the interest that has been given to the question of this so-called high elastic steel, and would like to remind the members of this Institution that the question whether a steel structure should be designed to have a factor of safety on its ultimate strength, or on its elastic strength, is one of considerable antiquity. It is a question that was frequently under discussion by French constructors, and very probably it would pay us, now that we are in possession of material with a longer range of proportionality or a higher elastic limit, call it what you will, to look up exactly what the French did, and apply their findings to present conditions.

There is one little historical matter that might very well have been added to Mr. Anderson's preliminary remarks, and that is some reference to our dear old friend the Rev. Dr. Ramus, who in the days of William Froude proposed a skimming vessel. The proposition was brought before the Admiralty; after much importuning it was considered by them and handed over to William Froude for investigation, and the results are buried in the usual Blue Book. A very interesting old Blue Book it is, as it shows, amongst other things, that any attempt to get a skimming vessel of ordinary proportions and speeds is foredoomed to failure.

Just one other point, may I express my disappointment that as a prophet Mr. Anderson does not foresee any change from the orthodox arrangements of the ship of the present day? The proportions of the accommodation that are given to passengers on board the present Atlantic liner are utterly absurd. There are a number of large public rooms, most of which are practically never used, full of gaudy, useless, and often tawdry decoration, never cheap, taking up a lot of space, a lot of weight, and a tremendous amount of money, and people, who pay perhaps as much as £10 per day, are compelled to spend the greater part of their time in sleeping

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Mr. W. H. Riddlesworth, M.Sc., M.Eng.
quarters which have been compared disadvantageously with cubicles in model lodging-houses, and things of that sort. I had hoped that the prophet would have told us that something better than that was coming.

Sir EUSTACE H. TENNYSON-D'EYNCOURT, K.C.B., F.R.S.: I think Mr. Anderson's paper is very interesting, as it crystallises the present position regarding the fast Atlantic passenger services, and gives much food for thought. He alludes to a paper which I read in 1924 suggesting that aircraft might be used in conjunction with passenger ships for speeding up the rate of progress at the beginning and end of a long sea trip, and although I think I mentioned the Atlantic route in that connection, I quite recognise the difficulties of flying off and on to a ship on that particular route, as I believe this could only be done, generally speaking, in comparatively smooth waters. What I had in view more particularly was the Eastern trade routes, where aeroplanes with mails, and passengers in a hurry, could fly off and on, linking up the places which were off the main steamer routes. This aspect of the question has been brought still further to the front, I consider, by the improvements made in seaplanes, which could take off and land, not necessarily on but near the ships.

Of course, the great objection to the very large 32-knot ship, of which Mr. Anderson gives particulars, would be its great cost. It might be well if this could be reduced by accepting, say, 30 knots as a speed, and also, it is not necessary to have such a fine block coefficient as ·52. Even with a 32-knot ship I think the block coefficient might be increased to ·575 with better economic results than ·52.

Regarding the open promenades which Mr. Anderson says would be impossible with a 32-knot ship involving special sheltered promenades, I do not think such promenades necessary, as ships with their present speed are often steaming

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Sir Eustace H. Tennyson-d'Eyncourt, K.C.B., F.R.S.

against a 15- or 20-knot breeze, or with it, which affects the relative wind more than the proposed increase in speed. Adequate shelter such as is now given, and perhaps somewhat increased, is all that is necessary.

Concerning the question of a skimming ship, to reach the skimming condition at 40 knots the vessel would have to be much smaller than that proposed, namely, 500 feet in length, or alternatively, the speed would have to be much higher than 40 knots before such a large vessel would lift out of the water and begin to skim, and I am afraid this condition would be very difficult to obtain, especially on the Atlantic. I quite agree with Mr. Anderson's final conclusion that future developments will be along orthodox lines, with a reasonably high speed and a comfortable ship.

Mr. A. C. F. Henderson (Associate): As one who is actually interested in the question Mr. Anderson raises, I consider his paper a valuable addition to the information on a subject which is occupying all our minds to-day. The historical part of the paper is no doubt of value and certainly interesting, but its most important feature is the endeavour to bring out all the various details of present type construction on the North Atlantic, and more or less to forecast what the future has in store in the way of Atlantic marine architecture. The latter point is a thorny and difficult subject, as all forecasts must naturally be, but it is all the more interesting on that account, and especially so in these days of high shipbuilding costs, for if shipbuilders could foretell the trend of future events they could approach the position with more confidence, and with probably a resultant decrease in tonnage cost. I should, therefore, like to confine my remarks to this phase of the paper, but before doing so propose to make one or two comments on the actual contents of the paper.

On page 170 Mr. Anderson makes some statements about the

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Mr. A. C. F. Henderson.

speed of the "Mauretania" and other ships in her class. The actual facts are as follows:—In 1924 the "Mauretania" made an average speed across the Atlantic of 26·06 knots, which has never been approached within 2½ knots by any other ocean-going merchant ship. At that time the "Mauretania" was 17½ years old, and the only record she then beat was her own.

On page 172 Mr. Anderson alludes to materials and economies in outfit on liners having induced economies in weight equal to about 10 per cent. I cannot at the moment check his percentage, but I fancy that cost has been more instrumental in the utilisation of these materials than the actual wish to limit weight, although this is most probably a contributory reason.

As regards the competition of airships and the remarks made by Mr. Oliver Simmonds at the British Association meeting in Southampton this year, I do not believe the day of the transatlantic airship has really yet arrived or will do so in the very near future. It must be remembered that the Atlantic passenger trade is not a constant trade all the year round, but is a very seasonal one, large masses of people being transported at some periods of the year and very few in others. In some weeks, for instance in the autumn, when the Americans are returning home, as many as 20,000 people are transported from Europe to the U.S.A. in a single week. Even allowing each airship to make two trips back and forward during the week, and also the very optimistic carrying capacity of 100 people per ship, this would mean a fleet of 200 airships in active service. I do not doubt the future competition of the airship, but her day as an effective factor, not to mention cargo carrying, is not to my mind in the very near future, nor do I regard with any idea of their more or less immediate adoption the conceptions set out by Sir Eustace Tennyson-d'Eyncourt at the Naval Architects' meetings in 1924, as a combination of ship and aeroplane can never be so satisfactory or economical, especially structurally, as either the ship alone or the airship proper.

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Mr. A. C. F. Henderson.

Mr. Anderson refers to Mr. A. T. Wall's suggestion of crossing the Atlantic by means of skimming vessels. This is a very attractive proposition, and would certainly go a long way to compete with the airship. For many reasons, however, it is entirely impracticable. In the first place, on the North Atlantic probably the worst weather in the world is encountered, and existing ships of much stouter construction have often all their work cut out to weather a North Atlantic winter. This, I think, is a sufficient reason, but to give two others, no ship which could not be used for more than half the year would ever be profitable, whilst the cost of developing 100,000 h.p. on the income derived from, at the maximum, 150 passengers is a financial and physical impossibility.

That is all the comment I wish to make on the paper, and now I will refer to what is, to my mind, the real trend of naval architecture as regards the North Atlantic trade.

In the days previous to the war, steamers engaged in this trade were, with very few exceptions, all vessels carrying three classes of passengers. They were divided into various classes as regards speed and luxury, but the distinctions were not so marked, especially with respect to speed, as they are to-day. There was the fast steamer or "monster" of 22½ knots and upwards, then came the steamers between 18 and 19 knots, the class of about 16 knots, and afterwards the slow steamers.

To-day the position is entirely different, and the classes are much more closely divided. The express steamer, of course, is still in evidence, although on account of the war and of initial cost the number is reduced to what it was before the war. After this there are a limited number of steamers round about 18 knots, but by far the largest number vary between 15 and 17 knots. Steamers slower than this, except purely cargo-liners, are comparatively few in number. By far the greatest change, however, has been in the type of ship, the large number of three-class vessels gradually but surely disappearing. The express vessel, of course, still continues to

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Mr. A. C. F. Henderson.
carry three classes, whilst a certain number of ships of from 17,000 to 22,000 tons still remain in the same category. The cabin and steerage ship has, however, grown numerically very largely since the war, and there development still continues. They are all ships of moderate and even large size, and in their appointments and luxury very closely approach, especially in cabin arrangements, to the first-class ship.

Concerning the future, the role of a prophet is always an unsatisfactory one, as he is almost always finally, if not earlier, proved to be wrong. At the same time the trend is so definite that it cannot be neglected, and I think it safe to say that the main classes of ships of the future on the North Atlantic will be the three-class "monster" express type, and the smaller type of cabin steamer. Respecting the latter, this will, I feel sure, be a still growing class, and in the economic conditions which exist to-day a class which the public really wants, as, owing to the high standard of comfort on these ships and the fact that outside the steerage they only cater for one class, a very important factor to a large number of people, they are in many ways practically equal to the three-class ship of to-day except in the matter of fares.

Coming to the future of the large, express type of steamer, it is difficult to forecast with such certainty what the future is likely to bring forth. One thing I think, however, is certain, that a large body of travellers will always prefer to make the passage on the largest and fastest ships afloat. This class is a constantly growing one, especially since the war. Mr. Anderson says it was predicted to him that the day is coming when liners will be running across the Atlantic at a speed of 40 knots. I do not know who made this statement to him, but as I have also made the same statement I cannot quarrel with it. At the same time the question of Atlantic speed requires careful consideration, as it is obviously ridiculous to increase a ship's speed, thereby landing passengers in Cherbourg in the middle of the night. The ideal speed is

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that which enables passengers to land at both Cherbourg and Southampton in order that they may reach London and Paris respectively at a reasonable hour. The following table will explain what I mean; in each case the time of leaving the dock in New York is 10 a.m. and Ambrose Channel noon on Saturday:—

AMBROSE TO CHERBOURG, 3,035 MILES.

Knots.	Sat. Noon.	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	Hours.
16	Noon	—	—	—	—	—	—	—	2.40 p.m.	194 11/16
18	,,	—	—	—	—	—	—	5.30 p.m.		173 11/16
22½	,,	—	—	—	—	—	7.53 a.m.			139 7/8
25	,,	—	—	—	—	6.24 p.m.				126 3/5
30	,,	—	—	—	10.10 p.m.					106 1/6
32	,,	—	—	—	3.50 p.m.					99 3/4
33	,,	—	—	—	1 p.m.					96 3/5

From the above it will be seen that the next step from 25 to 26 knots is a mean speed of 33 knots.

In conclusion, I might summarise my views as follows:—

1. The skimming boat or other known type does not seem suitable for Atlantic work.

2. The cabin ship type seems to be one that has come to stay, and will largely bulk in numbers on the Atlantic, whilst

3. The express type will undoubtedly remain, probably developing into ships of 1,000 feet in length, with a speed of 33 knots and upwards. I would not, however, in the meantime like to make any comments regarding the type of propelling machinery to be employed in these vessels.

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Mr. G. S. Baker, O.B.E.

Mr. G. S. BAKER, O.B.E.: There are one or two comments which might usefully be added to Mr. Anderson's paper. He has considered the development of flying only from the standpoint taken by Sir Eustace Tennyson-d'Eyncourt, namely, the utilisation of aeroplanes to shorten the time on the Atlantic passage; but I think it has a broader application than this. In aeronautics things are still in a state of flux, but there are quite evident signs that as soon as it is possible to make the complete Atlantic passage by air it will be done. In my opinion, this means the development of the large flying-boat of high speed. Already one of 32,000 lbs. displacement is in existence, capable of a long voyage at high speed, with ample room in the hull for passengers. If the demand for a rapid passage can be satisfied by air transport, to some extent there will be a falling off in the demand for extreme speed on water, and, therefore, less willingness to pay the price on the part of the passenger. Moreover, extreme speed on water can only be met by increase in size, or decrease in weight; even the 40 knots mentioned by Mr. Anderson must be attained under what is called "ploughing" conditions, *i.e.*, the ship must cut its own furrow through the water and cannot skim on the top, at that speed. This is quite definite if the ship visualised by him is considered. As a matter of fact, it does not pay (in power) to skim, unless the resistance exceeds roughly one-tenth the displacement, and I think a 500-foot vessel would do much better than that at 40 knots, with an ordinary ship shape of, let us call it, a super-destroyer type. Skimming vessels do not lend themselves to rough weather or to a troubled water surface. They are invariably very uneconomical at reduced speeds, and are most uncomfortable in even a moderately rough sea.

Vessels of destroyer shape can be and are built to stand quite rough usage, and when freed from war material would accommodate a fair number of passengers, but the price to be paid for speed even on these would be high. I think Mr.

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Mr. G. S. Baker, O.B.E.

Anderson's conclusion is a correct one, and that the very high-speed liner is not a likely development of the immediate future. Moreover, the space required on a ship's deck for settling and flying off, with even quite small aeroplanes, is very large, and the deck must be given a particular shape at the ends and sides for even moderate safety in flying on and off. The attempt to combine air and ship transport in this way would involve very large expense to serve a few passengers, and would mean more risk in the actual flight than if the whole passage were made by air. It seems more reasonable to suppose that these two means of transport will remain separate, and that the one will ultimately supply the demands of speed at any price, and the other of comfort and economy.

Mr. Edward Wilding (Member): The question of higher speeds and larger ships on the North Atlantic is entirely a commercial one. Progress in this direction depends on the shipowners rather than on the naval architect and marine engineer. The amount of money involved in these large ships at present prices is enormous, despite the progress which has been made in the various matters indicated by Mr. Anderson. Not many of these items tend to reduced cost.

There seems to be some fascination in the idea of the 1,000-foot, 30-knot ship, as, if my memory is correct, Sir John Biles wrote about this scheme between 25 and 30 years ago, and whilst it would technically have been difficult (though not impossible) then, it is quite feasible to-day, provided rates be paid by passengers and for cargo to cover expenses. There is grumbling at the present rates, which do not cover the expenses of slower ships, and speed is the most expensive luxury.

But there seems to me something unsound in the skimming proposal. Forty knots on a length of 500 feet corresponds only to 10 knots on 31 feet, and nobody would propose a skimmer for a 31-foot boat to do only 10 knots over open water, whilst any ship drawing only 10 feet 9 inches on a length of 500 feet

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Mr. Edward Wilding.

would have a bad time at least two days out of five on the North Atlantic, no matter what her form or power was. I, therefore, do not think a skimmer developed on the lines indicated can be expected.

Prof. PERCY A. HILLHOUSE, D.Sc. (Vice-President): In view of Mr. Anderson's ideas concerning the possibilities of the speed of Atlantic liners, I traced the gradual increase of speed which has already taken place by plotting the speeds attained upon a base line of years, and thus obtained a sloping line showing an average increase of about one knot in every five years. There are some ships, of course, ahead of that and some behind; but it may be inferred that 40 knots will be reached in the year 1940, taking the present speed at 25 knots and adding 15. There is, therefore, some time yet to wait until speeds considered by Mr. Anderson are attained. In the discussion which has taken place, Mr. Anderson gets too much of the credit, or discredit, for the skimming boat. Mr. Anderson's object in bringing forward the skimming boat was, it appears to me, merely to draw attention to it, and not to back it up or say that he believed in it.

Mr. ANDERSON: I wish to thank Prof. Hillhouse for his remarks regarding the misconstruction which has been placed upon my views regarding skimming vessels. The particulars in the paper were given to show the nearest approach to skimming, having in view the amount of fuel, etc., required for a voyage of over 3,000 nautical miles, and building a vessel of the minimum strength for service conditions. Remarks of a similar nature have been made in connection with the weights of the larger vessel, and I would ask those speakers to consult the paper again, and they will see, clearly stated, that I am only endeavouring to indicate the best that can be done under present known conditions. I would add, however, that I believe such weights as I have indicated could be attained to-day, provided the question of cost is not introduced, and

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that view seems to be borne out by Mr. Henderson's remarks. I would also state that, for problems such as this, it is not safe to base opinions of hull weights upon cubic numbers, as has been done by a writer to the press; each new problem must be fully analysed in order to reach a reasonably correct conclusion.

Mr. Denny's remarks upon length in relation to speed are very interesting, and there is no doubt that 40 knots could be obtained on a length of less than 1,000 feet, but, as he states, such a vessel would not be suitable for a voyage of 3,000 nautical miles. His remarks open up another point of view, however. If, for instance, we followed the lines indicated by our aeronautical engineers some time after the armistice, when they proposed to put down floating bases at certain positions across the Atlantic so that aeroplanes might land there to replenish their fuel and stores, then it would be possible to have a much smaller ship, but the *time* required between Cherbourg and New York would not be reduced, on account of the losses due to refuelling. The only advantage of such a scheme would be that a higher *speed* could be obtained with a smaller size of vessel. I am sorry that the naval architects of this Institution have not commented upon some of the bigger issues in connection with such a paper as this. I expected them to say more about the governing characteristics which might decide the sizes of vessels that could be employed, and amongst them I indicated the limitation of draught.

Is this matter of deep draught to high speeds and large vessels really essential? It is a vital point because it would determine, amongst other things, the sizes of docks, and in order to determine what effect a change of draught would have upon ship design I plotted out e.h.p. curves for three different proportions of vessels, retaining a length of 1,000 feet in each case. The example given in the paper has dimensions of 102 feet beam and 36 feet 3 inches draught. The alternatives were 117 feet 6 inches beam with 31 feet 9 inches draught—a

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Mr. John Anderson.
reduction of 4 feet 6 inches—and 91 feet 3 inches beam with 40 feet 6 inches draught. I found that the total e.h.p., for a block coefficient of ·52, differed in any of them by only about 800. In the case of the widest vessel it might be possible to have another boiler athwartships, which would mean a reduction in the total length of machinery space, and in that way it would be possible to arrange much more accommodation for passengers at little additional cost. I understand that a shallow draught and greater breadth would be a less difficult problem for civil engineers in the construction of docks suitable for the accommodation of these large vessels. I wish to make it clear, however, that these small differences are associated with a block coefficient of ·52; if the block coefficient were fuller, the differences due to proportions of breadth to draught would be greater.

I might comment upon the interesting remarks by Sir Eustace d'Eyncourt where he indicated that he thought a block coefficient of ·575 would give more economical results than ·52. I had always understood that when the speed was in the region of $\sqrt{L}$ the finer the model the better, but I would like to look into that matter further.

I would like to add a word of thanks to Mr. Marriner for the interesting remarks he made upon skimmers. Unfortunately I cannot apply any of them to the suggestions I have made, but I am quite sure they will be highly profitable to anyone who is making a study of skimming craft.

A great deal of the discussion has centred round the term "elastic limit" for steel, and a number of the speakers seemed to find difficulty in understanding what elastic limit means; the elastic limit is the point just before permanent set takes place. Metallurgists evidently have no difficulty in defining that position, but I am bound to say that, from the tests which have been made on compound structures, it would be difficult for practical experimenters to say just exactly where this limit occurs.

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THE COMMERCIAL APPLICATION OF FUEL OIL.

By A. F. Baillie.

1st December, 1925.

The use of fuel oil for industrial purposes has occupied the minds of most engineers during the past few years, and a description of the large number of purposes to which fuel oil may be applied, together with relative costs, will be, I hope, of some interest.

In the consumption of fuel oil as a heating agent it is first necessary to divide finely or atomise the fluid, so that it can be mixed with the necessary quantity of air to make the resultant a combustible mixture. This process is called "atomisation," and is effected by means of apparatus called "oil fuel burners." These burners are manufactured by various engineering firms, and come under three systems:—

1. Air-jet.
2. Steam-jet.
3. Pressure-jet.

The first system uses air under pressure as an atomising agent. Low-pressure air is blown from a motor-driven fan, although for special classes of work, such as the manufacture of electrical bulbs and other white glass ware, high-pressure air has in the past been used, and is supplied by blowers or compressors. For some particular classes of work it has been found an advantage to take all the air for atomising and combustion through the burner, and in this case the air is intermingled with the oil in the burner, the proportion being 207 cubic feet of air per lb. of oil. Thus, due to all the air being

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under control, an oxidising or reducing flame can be obtained at will. For other classes of work, the usual procedure is to take approximately 60 per cent. of air through the burners and induce the necessary extra quantity of air from the atmosphere to complete combustion.

The second, namely, the steam-jet system, uses steam under pressure as an atomising agent. It is usual to take the steam from an auxiliary stop-valve on the boiler or from a tee on the auxiliary steam-line, and reduce the pressure of the steam from boiler pressure to from 15 to 25 lbs. per square inch. The proportion of steam required for atomising, say Mexican fuel oil, is approximately ·3 lb. of steam per lb. of oil, or, on the other hand, say, from 1½ to 2 per cent. of the total steam evaporated. Again, with the steam-jet type of burner, the requisite amount of air to complete combustion is induced from the atmosphere.

The third, namely, the pressure-jet system, sprays the oil under pressure by means of a steam- or motor-driven pump, and also uses steam temperature to thin, or reduce the viscosity of the oil. This system has been developed during the last 15 years to such an extent that it is recognised as the most economical for burning oil under land and marine boilers. In this system oil is drawn from the storage tanks by means of a steam- or motor-driven pump through the suction strainers, and pumped through fuel-oil heaters and discharge strainers to the fuel-oil burners. The object of the suction strainers is to collect any foreign matter in the oil so as to protect the suction and discharge valves of the pump. The object of the heaters is to raise the temperature of the oil to such a degree that oil, when intermingled with sufficient quantities of air, is suitable for combustion. The object of the discharge strainers is that after the oil is passed through the heaters, a certain amount of foreign matter is released, and is then trapped by these strainers so as not to choke the nozzle of the burners, as the nozzles are very fine, ranging from

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1 to 2·5 mm. The hot oil under pressure issues from the burner in the form of a fine whirling mist, the process of which is termed atomisation. The necessary air for combustion is introduced through special furnace-fronts, which are fitted with dampers for controlling the air supply, and which slightly pre-heat the air, imparting to it a rotary motion in the opposite direction to the burner spray, in order thoroughly to intermingle and mix the oil spray and air supply, and so give complete combustion in the furnace.

These three types of burners have their various uses; the steam-jet system is used generally for small boiler plants on land, the pressure-jet system for large boiler plants and marine purposes, and the air-jet system for furnace heating and metallurgical work.

For comparative purposes, and assuming each of these systems tested under a steam boiler, a thermal efficiency of approximately 78 per cent. would be obtained for the steam-jet system, 80 per cent. for the air-jet system, and 85 per cent. for the pressure-jet system.

Land Boilers.

Probably the major portion of residual petroleum marketed in the United Kingdom is consumed under boilers, and the following figures show the comparative results obtained with oil and coal on identical boilers:—

Oil.

Date of test	7-8/9/22
Duration of test	24 hours 25 minutes
Number of boilers on test	One
Type of boiler	Galloway
Size of boiler	30 feet long by 8 feet 6 inches diameter
Heating surface	1,220 square feet
Normal rating of boiler (from and at 212 °F.)	10,200 lbs. per hour
System of firing	Clyde pressure-jet
Class of fuel used	Mex fuel oil

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Calorific value in B.Th.U's.	18,603
Specific gravity at 60°F.	·954
Draught (natural)	·55 inch
Steam pressure on gauge, lbs. per square inch	71
Temperature of feed-water	124°F.
,, ,, superheater	371°F.
,, ,, oil in tank	96°F.
,, ,, oil at burners	225°F.
Pressure of oil at pump, lbs. per square inch	125
Total quantity of water evaporated during test	246,294 lbs.
,, ,, ,, ,, ,, per hour (actual)	10,087 lbs.
,, ,, ,, fuel burned during test	19,537 lbs.
,, ,, ,, ,, ,, per hour	800 lbs.
Temperature of flue gas	404°F.
CO_2 recorded	11·6 per cent.
Factor of evaporation	1·17
Lbs. of water evaporated per lb. fuel (actual)	12·62
,, ,, ,, ,, ,, (from and at 212°F.)	14·8
,, ,, ,, per square foot of heating surface (from and at 212°F.)	9·65
Overall efficiency	76·8 per cent.
Percentage of normal rating	115·7 per cent.

COAL.

Date of test	8·9/6/22
Duration of test	24 hours 15 minutes
Number of boilers on test	One
Type of boiler	Galloway
Size of boiler	30 feet long by 8 feet 6 inches diameter
Heating surface	1,220 square feet
Grate area	40 square feet
System of stoking	Hand
Class of coal used	Welsh nuts
Calorific value	14,550 B.Th.U's.
Ash and clinker	16·2 per cent.
Draught (natural)	·7 inch
Steam pressure on gauge	73·4 lbs.
Temperature of feed-water	153°F.
Temperature of superheater	419°F.
Total quantity of water evaporated during test (actual)	158,456 lbs.
,, ,, ,, ,, per hour (actual)	6,534 lbs.

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Total quantity of coal burned during test	23,828 lbs.
„ „ „ „ per hour	983 lbs.
Temperature of flue gas	607°F.
CO_2 recorded	10·3 per cent.
Factor of evaporation	1·154
Lbs. of fuel per square foot of grate area per hour	29
„ water evaporated per lb. of fuel (actual)	6·64
„ „ „ „ „ (from and at 212 F.)	7·77
„ „ „ per square foot of heating surface (from and at 212 F.)	5·35 (boiler only)
Overall efficiency	51·5 per cent.
Percentage of normal rating	74

The advantages attaching to the use of oil firing for boiler plants are higher efficiency, increased capacity of plant, rapidity in adjustment to varying load, absence of smoke, dust, and ashes, saving in labour, and general cleanliness.

Comparative weekly running costs were kept of a battery of four Babcock & Wilcox boilers, and the appended results were obtained:—

WEEKLY COSTS.

	Coal.	Oil.
Labour for stoking coal and oil, 3 men at £5 per week	£15 0 0	£15 0 0
„ „ coal and ash handling, 5 men at £5 per week	25 0 0	—
Flue cleaning	0 1 0	—
Maintenance, labour, and materials	7 13 10	—
Capital cost of steam-raising plant—		
Coal, £3,000 at 10 per cent.	5 15 4	—
Oil, £1,300 at 10 per cent.	—	2 10 0
Cost of storage—		
Coal bunkers for 100 tons, £3,000 at 10 per cent.	5 15 4	—
Oil tank for 200 tons, £1,100 at 10 per cent.	—	2 2 4
Steam used for steam raising on oil	—	12 19 3
Electricity used for steam raising, coal carrying, and ash handling	9 9 0	—
Depreciation (longer life of boilers on oil)—		
Coal, £8,000 at 5 per cent.	7 13 10	—
Oil, £8,000 at 4 per cent.	—	6 3 0

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Fuel cost—								
Coal, 301·75 tons at 36/- per ton, including deterioration, etc.					543	3	0	—
Oil, 120·75 tons at 90/- per ton					—			543 7 6
Value of cleanliness in hotel					50	0	0	—
					£669	11	4	£582 2 1

Peak Loads.

Oil was employed for large and sudden peak loads in a large South of England power station, and it was shown that where the consumption of coal was from 4 to 5 tons, the consumption of oil for the same work was only 8 cwts., and, further, that oil met the peak load much more satisfactorily than coal.

Central Heating.

While dealing with the problem of land boilers, reference may be made to the success which has been obtained on cast-iron sectional boilers used for central heating; a definite parity in favour of oil against average grade coke of 2·5 : 1 has been maintained. Oil-burning units are available for as low ratings as 1,000,000 B.Th.U's. per hour, in which the oil and air supplies and boiler pressure are automatically controlled, and for which no attention is required except for lighting up.

Marine Boilers.

Fuel oil is used in steamships as a heating agent in the ship's boilers for generating steam to drive the main and the auxiliary engines, and it is the general practice to adopt the pressure-jet system of oil burning. The fuel oil used must have a flash-point of over 150 degrees F. closed to conform with Lloyd's and Board of Trade regulations. In most cases the pumping and heating equipment is placed in the boiler-room so as to be adjacent to the attendant, whose duties are in the stokeholds. In some cases, however, fuel oil having a flash-point as low as 79 degrees F. has been used. In this

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case, to conform with Lloyd's and Board of Trade regulations, it was necessary to install an isolated pump-room extending from the upper deck to the ship's bottom. In this isolated pump-room were placed the oil ends of the transfer pump and the boiler fuel-oil supply pumps, also the fuel-oil heaters. On the stokehold side of the isolated pump-room were placed the steam ends of the transfer pump and the boiler fuel-oil supply pumps. The reason for fitting this isolated pump-room was that any vapours which might arise from the fuel-oil heaters and boiler supply pumps would be contained within the pump-room and could not escape to the stokeholds, thereby eliminating danger of fires. To ensure further safety, a steam-driven suction fan was placed inside the isolated pump-room and controlled by an extension spindle from the stokehold. This fan was run periodically to clear any gases that might have collected in the pump-room. A lift was also fitted for the convenience of engineers and against any possible cause of gassing of the men.

Fuel oil when used on board ship is usually stored either in double-bottom tanks, cross-bunker tanks, deep tanks, or side pockets. In the early days of oil burning, fuel oil was pumped from any of these compartments into a gravity supply-tank placed on the main deck. From the supply tank the fuel oil gravitated to steam-jet burners placed on the furnace fronts of the boilers. In those days the steam used for atomising ranged between 5 and 10 per cent. of the total steam evaporated, usually nearer 10 per cent. Superintendent engineers then realised that they were losing a large quantity of steam when using this class of burner, and it meant either carrying a large extra reserve of feed-water or installing additional evaporators to cope with this loss of water. Steam-jet burners for use on board ship were finally discarded, on account of the afore-mentioned difficulties.

The next step taken was to introduce compressed-air jet burners for use on board ship. As the horse-power of

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vessels increased it was found that, to supply sufficient air for atomising by means of air-jet burners, the auxiliary machinery necessary was very large and cumbersome, and took up a lot of valuable space in the engine-room, and, furthermore, the maintenance charges were extremely heavy. For these reasons, the air-jet system was discarded.

The system used to-day is generally the pressure-jet system of oil burning, as already described. The modern method of using fuel oil on board ship is as follows:—

The oil is sucked from double-bottom or other tanks by means of an oil-fuel transfer pump discharging into two settling tanks placed in the stokehold, each of these settling tanks having a capacity of 24 hours' supply. The tanks are fitted with heating coils, giving at least one square foot of heating surface per ton of oil carried. The object of these heating coils is to reduce the viscosity of the oil in the settling tanks over a period, say, of 20 hours, so that if inadvertently any water has contaminated the fuel oil, it will settle out much more easily by the aid of heat. It will be seen, therefore, that to obtain 20 hours' heating in each of the settling tanks of 24 hours' supply, the fuel-oil transfer pumps should be of such a size as easily to handle the day's supply in about four hours.

From the settling tanks the oil is sucked by means of boiler fuel-oil supply pumps, and thence discharged through heaters and filters to the burners on the boiler front, as described above. At the bottom of the settling tanks, drain cocks are fitted, and connections led from them to a special pocket in the bilge in the boiler-room. A connection can also be taken from the suction side of the fuel-oil transfer pump, and another from the discharge side with a connection overboard, so that the drainage water from the settling tanks can be discharged overboard by means of this pump.

When using Mex fuel oil of ·95 specific gravity, it has been found that, with the exception of double-bottom tanks, it is

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not necessary to heat the oil to transfer it to the settling tanks. If double-bottom tanks are used, however, it is always advisable to have steam-heated coils in the vicinity of the suction pipes so as to reduce the viscosity of the oil, as in this case the oil has to be lifted, whereas, in the case of cross bunkers, deep tanks, and side pockets, the oil will flow to the pump. In the settling tanks, with the same class of oil, it should be heated up to at least 100 degrees F., as by this preliminary heating it takes a certain load off the fuel-oil heaters, as the oil has not to be heated up, say, from 40 to 260 degrees F. in one operation. Therefore, one operation is split up into two, namely, preliminary heating in the settling tank and a final heating in the fuel-oil heaters.

It is sometimes necessary for oil companies to use a fuel heavier than that supplied to shipowners, so as to ease accumulation of stocks at the refineries. This heavy oil is carried in the cross bunker adjacent to the boiler-room, and is handled through settling tanks, etc., to the burners. In this case the oil is usually heated up to about 135 degrees F. in the cross bunker, and in the settling or measuring tanks to about 180 degrees F., and finally in the fuel-oil heaters to a temperature of 270 degrees F., at which most efficient burning results are obtained.

To obtain actual running results on very heavy Mexican fuel oil, I took a trip across the Western Ocean some time ago. The following is a result of one of the series of tests carried out on one of the Eagle Oil Transport Company's vessels:—

DETAILS OF BOILERS.

Type of boiler	Single-ended Scotch marine
Number of boilers	Four
Length of boiler	12 feet, mean
Diameter of boiler	16 feet 3 inches
Number of furnaces per boiler	Four
Diameter of furnaces (inside)	$40\frac{7}{16}$ inches

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Type of furnace	Deighton corrugated
Total heating surface, all boilers	10,088 square feet
Combustion space per boiler	398 cubic feet
System of draught	Howden forced
System of fuel-oil burning	Wallsend-Howden pressure-jet

Details of Main Engines.

Type of engines	Quadruple-expansion, Tweedy balance
Diameter of cylinders	28½ inches by 41 inches by 48 inches by 84 inches
Length of stroke	54 inches
Steam pressure per square inch	220 lbs.

Details of Test.

Duration of test	120 hours
Weather conditions—	
State of atmosphere (barometer)	29·67 inches
Temperature of atmosphere	67°F.
Smoke at funnel top	Slight
Fuel oil—	
Specific gravity at 100°F.	·982
Calorific value in B.Th.U's. per lb.	18,500
Tons of oil consumed on test	195
,, ,, ,, per day	39
,, ,, ,, per hour	1·625
Lbs. of oil consumed per hour	3,640
,, ,, ,, per cubic foot of combustion space	6·09
,, ,, ,, per I.H.P.	·976
,, ,, ,, per knot	324
Temperature of oil in cross bunker	135°F.
,, ,, measuring tanks	170 to 190°F.
,, oil at burners	260 to 270°F.
,, air at fan	105°F.
,, ,, burners (top)	265°F.
,, ,, ,, (bottom)	225°F.
,, stokehold	110 to 118°F.
,, smoke-boxes	655°F.

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Temperature of uptakes	520°F.
,, base of funnel	475°F.
Pressure of oil at burners	100 to 120 lbs.
,, air at fan	$1\frac{5}{8}$ to $1\frac{3}{4}$ inch
,, ,, burners (top)	$\frac{5}{16}$ to $\frac{1}{2}$ inch
,, ,, ,, (bottom)	$\frac{11}{16}$ to $\frac{15}{16}$ inch
,, ,, base of funnel	$\frac{7}{16}$ to $\frac{1}{2}$ inch
Number of burners in use	16
Size of ,, ,,	No. 18
Number of heaters in use	3
Double strokes of fuel-oil pump per minute	8 to 9
Water—	
Temperature of sea	80°F.
,, feed-water	235°F.
Tons of water evaporated—	
On test (actual)	3,096·6
,, (from and at 212°F.)	3,201·7
Per day (actual)	619·32
,, (from and at 212°F.)	640·34
Per hour (actual)	25·8
,, (from and at 212°F.)	26·68
Lbs. of water evaporated—	
Per hour (actual)	57,803
,, (from and at 212°F.)	59,765
Per square foot of heating surface (actual)	5·73
,, ,, ,, (from and at 212°F.)	5·924
Per lb. of fuel (actual)	15·88
,, ,, (from and at 212°F.)	16·419
Factor of evaporation	1·034
Thermal efficiency	85·73 per cent.
Power developed, etc.—	
Total	3,729 I.H.P.
Revolutions per minute	66
Speed in knots	11·23

An interesting comparison was made by the American-Hawaiian Steamship Co. some years ago when they carried out actual tests on one of their vessels, the s.s. "Arizona," burning coal and fuel oil respectively.

The results obtained are given on the following page:—

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COMPARATIVE DATA: COAL *v.* OIL FUEL—S.S. "ARIZONA" ON TWO VOYAGES.

Covering passages from New York, Pacific Coast Ports, Hawaiian Island Ports, and returning to Philadelphia, *via* Straits of Magellan out and home.

Gross tonnage 8,672, Twin Screw, Three Boilers, Howden forced draught, Pressure 215 lbs., Quadruple-expansion engines.

Voyage.	Mean displacement out. Tons.	Mean displacement home. Tons.	Steaming time. Days.	Round voyage. Days.	Average speed Knots.
No. 3—Using coal -	16,882	16,660	143·33	186	9·01
No. 4—Using oil -	15,930	17,280	125·25	161	9·95

The actual cost of fuel consumed on those voyages was practically the same.

It will be noted that when using fuel oil against coal the average speed of this vessel was increased almost by one knot, and that 25 days were saved on the round voyage, 18 being saved owing to the increased speed, and seven owing to reduction in time of fuelling oil against coal. The boilers and engines on both of these tests were operated at their maximum capacities. The savings at the time in victualling, manning, and also the increased freight earnings, etc., together with the days saved per round voyage, amounted to approximately £4,000 per trip.

LOCOMOTIVES.

Locomotives in South America, the United States, and Eastern Europe have for many years been running on fuel oil in place of coal.

As far back as 1890 Mr. Urquhart converted a large number of locomotives from coal to oil firing on the Russian railroads, using Mazout as fuel. Of recent years, the principal change

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over has taken place on the Mexican railroads. In December, 1910, Mexican railroads were running on coal only; in June, 1911, 20 per cent. had been converted; in December, 1911, 80 per cent.; in June, 1912, 90 per cent.; and by December, 1912, the whole of the railroads had been converted from coal to oil firing.

In locomotive practice the steam-jet system of atomising is favoured, probably owing to its simplicity, and to the fact that it only requires a tee connection off the steam line for jetting purposes, and again, steam is always available in the round house for lighting up.

I understand the pressure-jet system of oil burning was tried on some of the Indian railroads some five or six years ago. The system was found to be economical, but, on the other hand, the heating and pumping unit was too cumbersome to be comfortably fitted into the cab of the existing locomotive. The objection on this score was so strong that the pressure-jet system was discarded in favour of the steam-jet. It may be interesting to view the following figures, which is a statement showing comparative tests with coal and oil on the Interoceanic Railway of Mexico. This railway connects Vera Cruz, on the Gulf of Mexico, with the Port of Acapulco, on the Pacific, and has a total mileage of 1,035.

One valuable feature of the use of fuel oil on foreign railways is the immunity it affords from the number of compensation claims, arising out of fires taking place due to the sparks from wood or coal engines setting fire to crops and forests. Some years ago the State Forester to the Public Service Commission of the United States strongly recommended a prominent American railroad to convert from coal to fuel-oil firing, in view of the frequent devastation of the adjoining country caused in this way.

In locomotive practice the cost of handling is also reduced. We learn that in the States, some few years ago, oil could be handled from tank cars to storage tanks and thence to loco-

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motives for about ·03 cent per ton, while the average for handling coal ran to about 5 cents per ton. Again, from experience, it is stated that the usual wastage of coal in handling between shipment and consumption is from 8 to 10 per cent., whereas when handling fuel oil such loss is entirely eliminated.

COMPARATIVE TESTS WITH COAL AND OIL, INTEROCEANIC RAILWAY OF MEXICO.

Test No.	Time running.	Miles run.	Speed.	Lbs. of water evaporated.	Lbs. of fuel used.	Water evaporated per lb. of fuel.	Gross weight of train in tons of 2,000 lbs.
			COAL.				
	h. m.						
1.	3 18	35·4	10·73	43,277	8,580	5·04	173·52
2.	3 28	35·4	10·20	41,575	8,140	5·11	173·50
3.	3 29	35·4	10·17	42,985	8,580	5·00	172·37
4.	3 34	35·4	9·92	46,106	10,340	4·46	173·64
5.	3 38	35·4	9·75	43,586	11,220	3·88	184·83
			OIL.				
1.	3 40	35·4	11·53	50,612	4,397	11·51	173·77
2.	3 16	35·4	10·81	46,699	4,390	10·64	176·11
3.	2 53	35·4	12·28	39,046	4,073	9·59	175·62
4.	2 33	35·4	13·88	41,591	3,833	10·85	163·74
5.	2 47	35·4	12·73	45,305	4,157	10·90	174·85

SUMMARY.

Time getting up 180 lbs. steam from cold - -	Coal, 98 minutes
Time getting up 180 lbs. steam from cold - -	Oil, 70 minutes
Improved speed with oil over coal (average) -	20·2 per cent.
Improved evaporation per lb. oil - - -	6·05 lbs. or 130 per cent.
Pounds of coal per 100-ton mile - - - -	15·07 lbs.
Pounds of oil per 100-ton mile - - - -	6·85 lbs.

There are no men required to load up the engine or clean out ashpans. There are no ashpits to empty, or ash to be

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loaded up and hauled away to be unloaded on waste ground. Fuel oil practically handles itself, and the man attending to the water pumps can also supervise the supplies of fuel to the locomotives.

In this country tests have recently been carried out on oil firing the Watt type of locomotive of the London, Midland & Scottish Railway (L.N.W. Section), this locomotive being in daily service between London and Birmingham. It may be of interest to state that 450 gallons of oil were consumed between London and Birmingham to pull a train having a total weight of approximately 400 tons. The mileage from London to Birmingham is 115, so that the consumption runs out at less than one gallon of oil per 100-ton mile.

In this locomotive the burner was placed at the tube-plate end of a special extension below the foundation ring of the fire-box taking the place of the ordinary ashpan. The flame is projected towards the rear end of the box, and thence deflected towards the tube plate. The ashpan has a false bottom formed of brickwork slabs curved towards the back end, in order to deflect the products of combustion upwards. The sides of the ashpan are lined with fire-brick to a point just above the foundation ring, otherwise the whole of the heating surface of the fire-box is available for steam generation.

Three burners are installed. The one in the centre, the main burner, is used when the locomotive is working at full load; the two wing burners are controlled by one valve, and are of a much smaller capacity, only being used when standing with steam up. The arrangement of these burners gives the best path to the flame and the products of combustion round the fire-box to the tube plate, so that in actual practice the whole of the fire-box is filled with flame.

A low arch is provided immediately over the burners in order that the heat of the first ignition of the oil spray may be concentrated and complete combustion effected as soon as possible. A small arch below the coal-firing door deflects the

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rush of flame from this door, and another arch across the centre of the fire-box deflects the flame all over the fire-box surfaces, and distributes it evenly over the tube plate.

A certain quantity of air is admitted through the burner casings. This air is not under control, and only provides the oxygen necessary for the initial combustion of the spray. A further portion of air enters the furnace from a number of small holes in the fire-brick false bottom of the ashpan, a few feet in front of the burner nozzle. Additional air enters through a damper placed in front of the fire-box, and is heated by its contact with the hot surfaces of the ashpan exposed to the flame. This air is then passed into the furnace, close to the back plate of the fire-box, and being highly heated in its passage is admitted to the furnace so as to provide the necessary oxygen to complete the combustion in the already ignited oil spray.

The steam for atomising is taken from the boiler line through a reducing valve, into a receiver, at a pressure of 15 lbs. per square inch. This receiver acts as a water collector, and is blown out periodically, so as to ensure dry steam reaching the burner. In the Scarab application of oil burning, before this steam reaches the burner it is passed through a calorised steel pipe, placed in the bottom of the fire-box in order to superheat the steam. It is stated that this calorised pipe is non-oxidisable at high temperatures, and has a very much longer life than an ordinary untreated steel pipe. A tee piece and control valve are fitted in the steam line, so that the engine can be started up from cold, either by taking steam from another locomotive or by means of compressed air in the round house. Steam is also led to a heater on the outboard side of the tank on the tender, so that oil may be heated up to reduce its viscosity between the oil tank on the tender and the burner on the locomotive. On the pipe line between the heater and the burner a steam connection is fitted, so that at the end of the day the line can be cleared of oil, otherwise difficulties

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might be found the next day when attempting to start up, due to the oil becoming much more viscous at the low temperature throughout the night.

The main oil tank is placed on the tender, and is fitted with a steam heating coil close to the outlet, so as to provide sufficient heat to enable viscous oil to flow freely from the tank to the heater. A thermometer is placed in the oil pipeline, to register the temperature of the oil, which acts as a guide to the fireman.

It is also advisable in cold countries, apart from the heating of the oil in the storage tank and in a special heater on its way from the storage tank to the burner, to have these oil pipes steam jacketed between the control on the cab and the burners themselves, so that the oil may reach the burners at a temperature of at least 100 degrees F.

Auxiliary to Coal.

In the early years of this century a French engineer introduced the subject of oil as an auxiliary, to which in the past little attention has been paid. The main advantages of auxiliary firing, he remarked, lay in being able to obtain at will a large increase in the power of boilers. The combustion of the petroleum does not in any way prejudicially affect that of coal; in fact, by the introduction of jets of petroleum, the condition and efficiency of combustion are improved by more completely mixing the gases. It is, therefore, not correct to consider the evaporative power of coal as identical when passing from ordinary to auxiliary firing, as the coal end efficiency should be largely increased. Admitting this as a principle, and supposing the quantity of water evaporated by the coal to be constant, the extra evaporation, due to the better mixing of gases, is credited to the petroleum.

Several evaporative trials were made with coal only and coal and oil firing on the same boiler of a French naval ship. When burning coal alone at the rate of 18·8 lbs. of coal per square

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foot of grate area per hour, and when burning coal and oil, in different proportions of oil at the rate of 21·3 and 21·7 lbs. of mixed fuel per square foot respectively, the results were as follows:—

Test No.	Fuel used.		Lbs. of fuel per square foot of grate area.	Water evaporated per lb. of fuel used.	Remarks.
	Coal. Per cent.	Oil. Per cent.			
1	100	—	18·8	9·05	
2	55	45	21·3	11·34	25 per cent. evaporative increase over No. 1
3	36	64	21·7	14·12	56 per cent. evaporative increase over No. 1

These tests are encouraging, and serve as a basis for further experiment, but the question was not developed until about ten years ago, when power station engineers started taking a keen interest in the subject.

The theory was that a poorer class of coal could be used in conjunction with oil fuel than could be burned satisfactorily under the boilers, due to the fact that the poor classes of coal tended to cake on the links of the chain-grate stokers, thereby retarding the necessary quantity of air from being drawn through the bars to complete combustion.

The result was that the poor classes of coal were merely covered with a smouldering mass, which travelled slowly along the bars and was dumped into the ashpit as partly consumed coal. This ash, on analysis, would probably have contained a very high percentage of combustible matter, thereby causing a very much greater quantity of coal to be burned per hour to maintain, say, the rated evaporation.

When fuel oil is applied, the theory is that owing to the almost perfect combustion obtained thereby, the combustible gases rising from the coal-fuel beds are quickly ignited, causing the top of this mass to become much more incandescent, thereby tending to airify the bottom mass, which would then

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allow sufficient air to be drawn through to complete the combustion of the rest of the poor-class coal.

So much interest was taken in this theory that the authorities of a large London power station gave their sanction for tests to be carried out under one of their coal-fired Stirling water-tube boilers. One burner was introduced into each side of the boiler, approximately 25 per cent. from the back of the grate, the burners being opposite one another. The fuel oil was stored in an overhead tank, capable of holding three or four days' supply. The oil then gravitated to the burners, which were of the Kermode steam-jet type, operating with steam as an atomising agent, at a pressure of about 25 lbs. per square inch.

The coal test was carried out on a nutty slack having a calorific value of 10,400 B.Th.U's., and a boiler efficiency of 69·25 per cent. was obtained. The temperature of the combustion chamber was 2,648 degrees F., and the uptake 660 degrees F.

The final of a series of experimental mixed-burning tests was carried out on a nutty slack having a calorific value of 10,300 B.Th.U's., and Mexican fuel oil having a calorific value of 18,750 B.Th.U's. A boiler efficiency of 74 per cent. was obtained, and the temperature of the combustion chamber was 2,850 degrees F., and the uptake 628 degrees F. The proportion of oil to coal on a B.Th.U. basis was 4·96 per cent.

It will be noted, therefore, that in addition to the previous claim of the pioneers of this system a large increase in the boiler rating can be quickly attained, and also that rated evaporation was much more mobile with mixed firing than with coal firing.

In a Yorkshire factory, in the wool-combing industry, the Lancashire boilers were fitted with auxiliary oil-burning apparatus. The steam generated was used partly for driving the factory, and partly for supplying boiling water for the wool-combing process. When using coal only, there was a

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period of 1½ hour in the morning, and again in the afternoon, when the demand for steam for heating water was so great that the driving engine was starved of steam, and its output was reduced accordingly. To overcome this difficulty, auxiliary oil-burners were fitted, and when the extra load came on, the burners were put in operation. A steady head of steam resulted, thus ensuring output to the full capacity of the plant.

Another method of using oil as an auxiliary is in iron works where metal is melted in a blast furnace and manufactured into pig iron. The iron ore is placed in the blast furnace. During the process of melting certain gases are given off; these are collected, piped to the boiler-house, and used as a heating agent. The boiler generates steam, the steam is piped to the blowing engine, the blowing engine generates air, which is passed through a heating chamber. This air finally reaches the blast furnace, and is intermingled with the gases of the coke to form a combustible product.

In some qualities of ore the calorific value of the gases given off is poor. Now when this happens the steam pressure from the boiler will drop, owing to sufficient heat not being applied. In former days coal was then thrown on to the grate to assist in maintaining steam pressure. The furnace in a cold state, due to the low calorific value of the gases, was not incandescent enough to produce gases from the coal to form combustion. Therefore, the steam pressure dropped, the air pressure to the blast furnace dropped, and consequently the output of the blast furnace dropped.

To fire the coal and raise the steam pressure to the requisite amount would take from 1 to 1½ hour, and, due to this lost time, it would take from 7 to 9 hours at full steam pressure to bring back the blast furnace to its proper working condition.

Now, by the modern application of oil fuel in place of coal, if a bad patch of gas comes through, instantaneous combustion will take place as soon as the oil burners are turned on,

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and the steam will be maintained at one uniform pressure, the air pressure to the furnace being maintained, and an output of so many tons per hour guaranteed.

Some few years ago this method of auxiliary oil-firing was fitted to a blast-furnace plant, and results noted over a period of a month. The cost of oil as against coal was slightly less, and when using oil an increase of from 8 to 9 per cent. of finished pig iron resulted.

Glass Furnaces.

In the glass industry, oil fuel has already been applied to tank furnaces producing both green and colourless glass, pot furnaces, lehrs, and glory holes.

The average glass tank in this country is not designed to burn oil, but is usually a conversion from coal firing or gas firing. When making these conversions the same efficiency can scarcely be expected from the converted tank as from a new tank designed for oil burning. Even when a new tank is built to be oil fired, usually the owner of the tank will not go to much expense in order to put in recuperative facilities and so obtain the greatest efficiency, but prefers to have a cheaply built furnace and use more fuel when running. The ideal type of furnace is, I think, that in which, after the products of combustion have done their work in melting the glass, they should be passed into an air heater for heating the burner air, then into a waste-heat boiler which drives the air compressor, then through a feed-heater or economiser and into the stack at a temperature of from 200 to 300 degrees F. With a furnace run on these lines the utmost overall thermal efficiency would be obtained.

In an oil-fired glass tank of approximately 15 to 20 tons capacity, as used in this country, two burners are fitted about four feet apart in the back wall into small combustion chambers, the centre of the burners being approximately 12 inches above the level of the glass in the tank. The cullet and batch

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are usually fed in through a door between the burners. The oil flame plays across the top of the cullet and batch. The waste heat is drawn off by flues at the front end of the furnace and passes straight into the stack.

The burners on a furnace of this type use air for atomising the oil at a pressure varying from ½ lb. to 3 lbs. per square inch, depending on the type of burner used. The air is supplied by a blower or high-pressure fan. The air pipe should be led over the furnace top to heat the air, as the hotter the air the better the oil is burned, and the greater the efficiency obtained.

The oil is supplied from a storage tank on the ground level to a small overhead supply-tank above the furnace at the back end, from whence it flows by gravity to the burners. The oil pipes again should be led over the furnace top to pick up waste heat, in order to facilitate atomisation. The correct temperature at the burners for burning Mexican oil is from 140 to 150 degrees F. On a glass tank of this description 2·73 lbs. of finished glass were produced per lb. of oil used.

The oil firing of large regenerative tanks previously fired by producer gas should be carried out in the following manner. Suppose that the tank is fired by four gas ducts on either side alternately for half-an-hour's duration. In order to convert this tank for oil burning, the gas ports should be blocked up, the air ports redesigned, and the furnace crown lowered. Oil burners should be fitted into the top of the four gas ports as they enter the furnace, two burners being fitted to each gas port. The burners should be of the compressed-air type working at a pressure of about 15 lbs., and given a downward tilt in order that the flame might play on top of the molten glass.

The furnace is worked in the same manner as when it is burning gas, that is eight burners on the right side are fired for half-an-hour, whilst the eight burners on the left side are

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shut down, then the right eight burners are shut down and the air valve is changed over, the left eight burners being then put into operation. The secondary air-temperature at the start of each half-hour run, in passing through the regenerators, would be about 1,200 degrees C., and at the finish of the half-hour run it would be about 700 degrees C.; the oil temperature should be about 71 degrees C. The primary air temperature is approximately at atmospheric temperature, as it is not heated except for radiant heat picked up from the furnace.

Pot Furnaces.

There are very few oil-fired pot furnaces in this country, and what few have been tried have not been entirely successful, the chief trouble being the cracking of pots, due to excess of local heat. I think the ideal oil-fired pot furnace would be one with the pots set round in a circle with an exhaust port between each pot and a burner playing up in the centre on to a dome-shaped roof. This would enable the heat to be distributed evenly all over the pot, but up to the present a suitable burner has not, as far as I am aware, been manufactured in this country for this type of furnace.

Lehrs.

Usually when the main glass-tanks are oil fired, the lehrs are oil fired also, the oil firing of the lehr being run from the main oil-line, and as a rule a smaller burner is required for the lehr. The burner fires into the lehr longitudinally through a small combustion-chamber, where the products of combustion are taken up by a vertical flue on either side of the lehr, and passed over a bridge into the lehr itself, the hot gases passing over the bottles to be annealed. The application of oil burning to a lehr is very simple, and is usually very effective.

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Glory Holes.

The application of oil-fired glory holes with heavy fuel-oil is rather difficult if the glory holes are separate from the glass tank. When incorporated with the main glass-tank they are worked in a similar manner to the drawing-off holes. When they are worked separately, usually a light grade of oil has to be used on account of the formation of carbon. The reason of the formation of carbon is that the burner works in such a short space that the combustion is not complete before it reaches the bottom of the glory hole, and in consequence a deposit of carbon is formed. Some glory holes have been worked on paraffin very effectively, and they are found to be cheaper than those worked on light-grade oil, due to the fact that paraffin can be gasified, whereas the other oil can only be atomised.

Industrial Furnaces.

One of the earliest applications of direct oil-firing was to furnaces for metallurgical and industrial processes, such as rivet and bolt heating, crucible, case hardening, annealing, core drying, billet-heating furnaces, and galvanising baths. The main advantages of fuel oil are increased output, reduction in cost of fuel required for a given amount of work, less waste, perfect control of temperature, and prolonged life of furnaces. Fuel oil is largely used as a heating agent for billet heating for drop stampings.

The furnace is usually of a rectangular shape fitted with an air-jet type of burner at one end, and a counterblast at the other end, the handling door being in the sides. The air pressure is usually obtained from a fan giving a pressure up to 28 inches water gauge. Both the air and oil supply should be preheated by the exhaust gases on their way to the burner. The oil consumption per 100 lbs. of metal heated for drop stamping is approximately 9 lbs. Again, the nut and bolt makers are large users of fuel oil.

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The construction of the furnace is on similar lines to that of a billet-heating furnace, except that it is usual on a bolt-making furnace to work two sides, and in some cases four sides are worked. The round bars for the bolts are cut to length cold, then the pins, as they are termed, are put separately into a hole in a special brick let into the side of the furnace. Thus only the end to form the bolt head is heated. The nuts are made from flat bar material heated the full length that it will go into the furnace. The nuts are then stamped off hot. The consumption on a nut-making furnace gives approximately 4 lbs. of oil per 100 lbs. of the metal heated, and a bolt-making furnace 4·5 lbs. of oil per 100 lbs. of bolts produced.

A test on a bolt-making furnace 9 inches by 12 inches by 20 inches, in the Midlands, gave from 400 to 500 gross of ¾ to 1-inch diameter bolts per week, on a consumption of 300 gallons of oil.

The rivet-heating furnace is another type of furnace to which oil has been applied successfully A large Clyde firm, on a three weeks' test, turned out 4 tons 8 cwts. of heated rivets on a 118-gallon consumption of oil, which gives 10·3 lbs. of oil per 100 lbs. of rivets heated.

The outstanding features in using oil on the above types of furnace is the increased production, which is from 100 to 400 per cent., depending on the class of work and conditions, and the great saving in floor space.

The metal-melting industry offers great scope for the use of fuel oil, and it is used extensively in brass, aluminium, and cast-iron melting furnaces.

Brass and aluminium are usually melted in lift-out types of furnace. These consist of a plumbago crucible set in a cylindrical furnace, in the case of a single furnace, and an air-jet burner is applied tangentially at the bottom, so that the flame rises in a spiral round the pot. In the case of a battery of pots, the burners are placed at both ends of the battery.

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For larger type brass-casting work a tilting furnace is employed, which consists of a pot holding 600 lbs. in a furnace, the whole mounted on trunnions, so that the pot can be tilted for pouring.

For still larger melts an open-hearth type of furnace is employed, holding about three tons of metal. The burner in this case plays across the top of the metal, and the molten metal is removed by means of ladles.

The following results have been obtained on the above types for gun-metal melting:—

Tilting furnace—10 lbs. of oil per 100 lbs. of metal (finished).

Open-hearth furnace—10 lbs. of oil per 100 lbs. of metal (finished).

Lift-out furnace—12·5 lbs. of oil per 100 lbs. of metal (finished).

The chief advantages in using oil are increased output, increased life of pots, and decreased metal losses.

Cast-iron melting and steel making is usually carried out on a "Stock" converter furnace. This consists of a large egg-shaped wrought-steel receptacle, brick lined and balanced horizontally on trunnions. The charge is from ½ ton to 3 tons of pig iron. The oil is forced into the burner hot at a pressure of about 40 lbs. The air for atomisation is preheated, and blown in at a pressure of from 1½ to 2 lbs. After the pig iron has reached the necessary state of fluidity, the oil is shut off and air alone at a pressure of from 3 to 4 lbs. is blown through, which converts the pig iron to steel. On this class of furnace the oil consumption is 15 lbs. per 100 lbs. of metal for melting only, and 40 lbs. per 100 lbs. for total fuel consumption, including lighting and heating up.

Another field in which fuel oil is used is steel melting. The following results were obtained by an Italian firm using

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fuel oil for heating open-hearth Siemens-Martin steel furnaces:—

The furnaces are basic of 65 tons capacity, four in all, 36·08 feet long by 16·4 feet broad by 10 feet high at the centre of the arch. There are five charging doors, and each section is built on the separate arch principle. The furnaces are charged with molten pig-iron from a large mixer. The temperature obtained is 1,650 degrees C., with an output of 150 tons of steel per 24 hours per furnace on an oil consumption of from 16·5 to 18·75 tons, which gives from 11 to 12·5 per cent. fuel consumption. The air for atomisation in this case was 57 lbs. per square inch.

On a galvanizing bath a saving of 10d. per ton on a total output of 600 tons was obtained, and the weekly consumption of oil was 3 tons 10 cwts., against 7 tons 10 cwts. of coke per bath.

The above furnaces are some of the types to which fuel oil is being applied. There are also many more classes of heat treatment of materials to which fuel oil is, and can be, applied at the present time.

Discussion.

Mr. JOHN S. BROWN, M.B.E. (Member): It is presumably some qualification for opening the discussion on Mr. Baillie's interesting review of the uses of fuel oil to say that the war period afforded me an opportunity of taking an interest in the consumption of some 30,000 tons of oil in a marine installation. This plant operated on the pressure system with forced draught. On a service where the demand for steam varied very widely, and where, at best, the periods in harbour involved full steam being available at a few hours' notice, there can be little question that the convenience could be allowed to outweigh all the other factors. But the fuel costs, compared with coal, would require to be heavily adjusted in

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Mr. John S. Brown, M.B.E.

terms of the reduced stokehold complement before any commercial advantages could appear. Further, I believe there were periods when considerable anxiety was felt regarding the maintenance of the oil supplies to the North Sea bases; as evidence of this there is a war relic in the form of a pipe line from Old Kilpatrick to Grangemouth. These matters need not be enlarged on, as Mr. Baillie has quoted numerous other cases where the convenience has again a definite financial value. But in the instance where there is a fluctuating demand for power, an alternative is provided in the steam accumulator, as described recently by Mr. Taylor.

The experience I have mentioned allowed an examination to be made of the conditions under which the oil was burnt most economically. When the pressure at the burners was raised to the limit permitted in the system, the ship advanced to the head of her class, as measured by less oil being used than on the sister vessels when passages were made in company. In this light there is occasion to ask what special claims can be made for the systems which operate at low pressures, as a pump is necessary in any installation, and is generally of a form which would give 150 lbs. per square inch as readily as a lower pressure. Further, in the steam-jet system, is there any definite reason for reducing the steam supply to 25 lbs. per square inch? Surely the atomisation would be improved if the full boiler pressure were available.

At that time there were also opportunities for comparing notes with oil-fired vessels of the American Navy, and it was learned that in them the oil was heated to 300 degrees F., in place of our limit of 200 degrees F. No difficulties followed from this further heating, and, again, it would improve the atomisation. Perhaps we might be told something of the factors which fix these operating temperatures. In neither of these cases were settling tanks provided, the oil being fed directly to the burners from the double-bottom and other

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tanks. Little trouble arose from water being present in the oil; and, subject to the oil being free from water when delivered on board, the handling of all the oil through these tanks is regarded as purely a precautionary measure.

The growth of the system of oil storage tanks in the Old Kilpatrick area may be taken as evidence that the engineering industry is to be given opportunities for using considerable quantities of this new fuel, and I have, therefore, found this paper of great interest. No reference to the Diesel engine appears in the paper, and with the title limiting it to "Commercial Applications," I would ask whether the oil companies find this engine so sparing in its use of oil that, to them, it is not a commercial proposition?

Mr. WILLIAM C. MCGIBBON (Member): When oil burning was first introduced on board ship, I had quite a number of pupils from Singapore who used to declare that after a voyage there was always one man left in hospital. Perhaps that was due, to some extent, to incompetence, but the cost of his treatment should have been set against the fuel account.

Referring to the weekly running costs of the battery of four Babcock & Wilcox boilers, Mr. Baillie gives the labour cost for stoking coal and oil as £15 for three men in each case, which seems to me a very high rate of wage for such labour.

Eng.-Capt. W. ONYON, M.V.O., R.N. (Member of Council): Last week, in London, I was fortunate enough to hear Admiral Sir Edmond Slade on "The Supplies of Oil Fuel in War Time," and it was interesting to learn from him that over 70 per cent. of the oil in the world comes from the North American coast, and 21 per cent. from Mexico. It is not difficult to discover from his paper that Mr. Baillie has a close connection with the Mexican Oil Co., and I should like to ask him a few questions. Fuel oil is often purchased from the

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Eng.-Capt. W. Onyon, M.V.O., R.N.

Anglo-Mexican Oil Co., that is the Shell-Mex, for burning under boilers and also for use in internal-combustion engines, and there is a great difference in price between the two grades. I would like to ask Mr. Baillie if the difference is due altogether to the difference in quality between the oils, or is it partly due to freight rates from the different parts of the world from which the oil comes?

I managed to extract from Admiral Slade that the best Diesel oil comes from the East. The fact that the temperature of the oil has to be raised before burning it under boilers is one which gives an engineer much concern. I always understood that the temperature had to be raised above the flash-point of the oil before burning it. Perhaps Mr. Baillie can say what is the best temperature to which oil for burning under boilers should be heated. It certainly should have some reference to the flash-point of the oil.

I served in H.M.S. "Dreadnought" from 1906 to 1908, in which the boilers were fitted to burn oil as well as coal. In a ship subdivided like she was, it is quite obvious that the amount of coal available per boiler varies according to its position in the ship, and for a long voyage fuel oil must be used to level things up. The boilers were usually lit up with coal, and burned with the draught plates open for nine hours, when the furnaces got dirty and required cleaning. The draught plates were then closed, and oil was burned on top of the dirty coal for 18 hours, when one boiler at a time was shut down. That was the method adopted to enable the ship to cross the Atlantic. This system makes an enormous amount of smoke, which, for obvious reasons, is not desirable in a warship.

Mr. R. F. Jones (Member): I notice Mr. Baillie classifies the various oil-burning systems as air-jet, steam-jet, and pressure-jet, and had he not stated the various thermal efficiencies later on in his paper I would have taken exception to the order given. I do not understand why the steam-jet is

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introduced between air- and pressure-jet. The pressure-jet system, which is probably the most interesting to members of this Institution, has undoubtedly reached a very high standard of efficiency, and its simplicity of control, especially on board ship, is unequalled. Mr. Baillie credits it with 85 per cent. efficiency, and I quite agree with him. In fact, I am inclined to think that it is slightly higher when working under forced draught with preheated air.

Regarding the air-jet system, I again agree that 80 per cent. efficiency is quite a reasonable figure, but am of the opinion that for certain applications it has advantages over both pressure- and steam-jet systems, a fact which many engineers do not yet realise. I have in view a Diesel-engined vessel in which the auxiliaries are driven by steam from a vertical type of boiler. When the vessel is running at sea it can be assumed that all the steam required will be for the steering engine, a bilge pump, and possibly a little for heating purposes, and this total amount will necessarily be very small. The steam-jet system can at once be ruled out of the question, on account of the loss of fresh water used in jetting the oil, while the pressure-jet system has two features which render its application unsuitable for this purpose. (1) The minimum quantity of oil which the system can burn down to is about 100 lbs. per hour, giving approximately 1,300 lbs. of steam per hour, and only a small percentage of this will be required to drive the aforementioned auxiliaries. (2) In Diesel-engined vessels it is frequently found more convenient to place the boiler in the 'tween decks, which entails a reduction of draught due to a reduced height of chimney; and even if the height were increased by 10 feet there would invariably be insufficient draught when the maximum output was required for discharging cargo with all winches working.

The low-pressure air-jet system of oil firing is the only one which can meet these conditions, as by its use oil can be burned to a limit of 10 lbs. per hour when running at sea, and to a

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Mr. R. F. Jones.

certain extent it is independent of chimney height, since the air delivered by the fan induces the necessary amount to complete combustion.

Mr. Baillie credits the steam-jet system with an efficiency of 78 per cent. I do not agree with this figure, and in my opinion 70 per cent. would be extremely good. I have carried out a considerable number of tests on boilers fitted with this method of oil burning, and have never known a case where the efficiency was over 70 per cent.; in most cases it was considerably lower.

Referring to the test on the Galloway boiler, I presume that Mr. Baillie's figures for the calorific value of the oil is the gross value; and assume that the boilers were not working in conjunction with economisers; had they been included I should expect at least an efficiency of 82 per cent. In the case of six Lancashire boilers on which I carried out a test extending over six hours, I obtained an evaporation of 15·5 lbs. of water per lb. of fuel from and at 212 degrees F., which is equivalent to an efficiency of 86 per cent.

To those who have carried out experimental work on oil burning, I am quite sure they will look with great interest to Mr. Baillie's remarks on central heating boilers. In the first place, the sectional cast-iron boiler has been designed as the result of long experience in connection with coke firing. Being of cast-iron, any severe impingement of the flame on the metal must be avoided. The position of the door is also somewhat detrimental to oil firing, so that anyone who makes progress with central heating deserves credit.

I see no great prospect of making oil firing of locomotives a commercial success. In locomotives the draught is artificially created by the exhaust from the engine, which renders it very difficult to control, and militates against a high thermal efficiency, and since the least efficient method of oil burning, namely, the steam-jet, is generally applied, it is possible that only countries like Mexico, the Argentine, and some areas in

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Mr. R. F. Jones.

the U.S.A. will adopt oil burning as standard practice for locomotives, due to cheap oil and dear coal.

I quite agree with what Capt. Onyon says about auxiliary firing, and can see few advantages to justify its use.

With regard to plate- and rivet-heating furnaces, I concur with Mr. Baillie, and consider that furnaces of this nature will all ultimately use liquid fuel, provided that it can be purchased at a reasonable figure.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Member of Council): In his paragraph on central heating Mr. Baillie makes the comparison of 2·5:1 in favour of oil. Will he please state if that is cost, or what it is? My next point has reference not to oil-burning but to something that casually appears in connection with locomotives. Mr. Baillie says, "We learn that in the States, some few years ago, oil could be handled from tank cars to storage tanks and thence to locomotives for about ·03 cent per ton, while the average for handling coal ran to about 5 cents per ton." I am perfectly certain that in this country coal cannot be handled at 2½d. per ton; it would be much more like 5/- per ton. Perhaps Mr. Baillie will be able to enligten us on this point.

My other point is in confirmation of some of Mr. Baillie's remarks about industrial furnaces. He has omitted what I consider to be perhaps the greatest advantage that oil possesses for industrial furnaces, and that is the ease with which it can be lighted up and closed down. In a shipyard, furnace work is a casual sort of job. There is something to do in the furnace to-day, nothing to do to-morrow, and there may be another job the day after. Some of the furnaces, the frame furnaces for example, can be lit up and kept going for weeks, maybe for months, but the plate furnaces are frequently wanted for a short time only, and in practice they really do effective work only now and again, and in either case only for a few hours each day. Therefore, such a fuel as oil,

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Mr. W. H. Riddlesworth, M.Sc., M.Eng.
which can be turned on and off at will, and be ready for use at an hour's notice, is much more advantageous than one requiring more steady conditions.

With respect to rivet heating, I can quote from some of my own measurements figures which confirm those given by Mr. Baillie. Rivet-heating furnaces are very conveniently made to burn oil. I am quite well aware that they can equally conveniently be made to burn town's gas, but oil is very easily obtainable, and the furnace can be readily moved from place to place as wanted. I have a record which shows that, in a series of tests using about 500 lbs. of rivets, the average oil consumption was 16 lbs. per 100 lbs. of rivets heated. The best group of results over one hour's run was about 9 lbs. of oil per 100 lbs. of rivets. But all such records require to be qualified with the condition that the actual output of heated material depends entirely upon the man who is working the furnace, and upon the demand and his response to it. In any of the tests referred to, I felt certain that not less oil would have been burned if only one-quarter of the number of rivets had been heated. That is one of the defects of any furnace for intermittent use, which perhaps some day may be removed. Some electric heating appliances use energy exactly in proportion to the weight of material heated, but suffer from the defect of using a very costly form of energy.

Mr. R. J. Butler (Member): A great compliment to Mr. Baillie has been paid by the number of questions asked during this discussion, and I wish to add my quota to these, in the hope that he will enlighten us on the points raised. Mr. Baillie gives figures for what he calls the thermal efficiencies of the three different oil-burning systems, quoting 85 per cent. for the pressure-jet, which is an extraordinarily good figure to obtain, and means that everything has to be tuned to the utmost limit; it cannot be regarded as an everyday attainment. I presume that Mr. Baillie intends these figures of 78, 80,

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and 85 per cent. to be rather the relative limiting efficiencies over all of the steam-raising plant, and not really the thermal efficiencies of the oil-burning system *per se*.

In the comparative tests of coal and oil firing, I think Mr. Baillie is scarcely just to the coal-fired job. It is hardly fair to make a comparison with an oil-fired boiler by taking the efficiencies obtained from a coal-fired boiler simply on that one test and making deductions therefrom. The coal-fired boiler is being stoked at 29 lbs. per square foot of grate area, which rate is reflected in the high flue-gas temperature of 607 degrees F. compared with 404 degrees F. of the oil-fired boiler, so that a high efficiency can scarcely be expected.

The capital cost of steam-raising plant for a battery of four Babcock & Wilcox boilers is given as £3,000, and £1,300 for coal and oil respectively, or a weekly cost of £5 15s. 4d. and £2 10s. I am not clear what that means, as further on in the table there are quoted depreciation figures at 5 per cent. and 4 per cent. on £8,000. Moreover, the inclusion of 1s. per week for flue cleaning in a bill of £670 appears ludicrous. The real criterion of cost per lb. of steam evaporated is quite ignored.

With regard to Mr. Baillie's account of a trial of one of the Eagle Oil Transport Company's steamers, the figures quoted for the total water consumption run out to about 16 lbs. per i.h.p. per hour, which is high for a large slow-running quadruple-expansion engine with few auxiliaries; about 14½ lbs. would be a more probable figure. I should like to ask Mr. Baillie how the water was measured in the ship. It is my experience that the most accurate way of measuring water is by means of tanks. Results obtained by any other means are open to grave doubt at the best. If this figure is high, then, of course, the boiler efficiency deduced from it is unreliable.

A recent large equipment in which I was interested has given a combined boiler and superheater efficiency of 85 per cent. without intensive air preheating; this would appear to be the maximum that can be expected. Unfortunately the CO_2 per-

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Mr. R. J. Butler.
centage is not quoted, so that the excess air supplied cannot be calculated to check the high efficiency shown.

In marine work, no engineer who had had experience with fuel oil would ever desire to go to sea in a ship that burned coal, as the stokehold is the worst part of the machinery spaces. With oil it is certainly the most comfortable place, and these conditions make for the attainment of a human efficiency—apart altogether from that of the plant—quite impossible with coal firing.

Mr. C. R. H. Bonn (Associate Member): Probably the most important point concerning a fuel oil, after the calorific value, is its viscosity. The viscosity determines the temperature to which the oil in the tanks must be brought for pumping, the temperature in the settling tanks necessary to eliminate the water in a given time, and the temperature to which the oil must be raised in the heaters in order that it will give satisfactory results for a given orifice and pressure at the burner; it is, therefore, necessary that the viscosity-temperature curve of an oil should be known. Without such a curve, the oil temperature figures, such as those given on pages 204 and 210, are meaningless. Could Mr. Baillie not give such curves for these tests with the given temperatures marked on?

From the question of temperatures, it is natural to turn to that of heating areas. The heating area to be provided in different tanks is a matter of prime importance to engineers and shipbuilders, for should the heating area provided turn out insufficient, it is a very serious matter. Expensive delays in port have occurred owing to the insufficient provision of heating areas or an insufficient steam supply. Only once in the course of his paper does Mr. Baillie give a figure for the heating area, and this again is of little use, as the nature of the oil is not disclosed. The question of the amount of heating area to be provided is complicated by the shape and

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position of the tank. For instance, an oil of high viscosity may be taken from a comparatively deep tank by the oil-fuel transfer pump with only a heating coil at the strum. The temperature at the strum in this case might easily be well above the flash-point. It is further complicated by the fact that a high viscosity oil might have a comparatively low flash-point. Crude oils have been shipped without topping, of such high viscosity that it has been difficult to get them out of the tanks without heating them above their flash-points, thus endangering the ship.

As the consumption of oil goes up, the tendency is to ship heavier and heavier oils, and this matter of heating becomes of increasing importance. This appears to be an excellent opportunity for Mr. Baillie to give some useful information on this point.

The success of oil is very qualified. This is the more evident when such figures for costs as those given in the paper are put forth in support of its greater economy. No doubt oil will always have its special fields of use, but imminent developments in power engineering and synthetic chemistry, encouraged by what appears to be the artificially high price of oil, and supported by the policy of such countries as Great Britain, which has no natural supply, are going to compel the great organisations which control the world's mineral oil supply to look to their laurels in the near future.

Mr. James O. Baird (Member): I must confess to a feeling of disappointment that in a paper entitled "The Commercial Application of Fuel Oil" some more definite guide is not given on the question of the most economical fuel to use at varying costs. If the prices of coal and oil ascended and descended simultaneously, this would not be of so much importance; but, as there is no fixed price ratio, it would be interesting and of value to know at what cost ratio oil becomes a more economical proposition than coal.

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Mr. James O. Baird.

Other factors besides primary fuel cost certainly enter into the problem. Ease of handling and storage in remote spaces weigh in favour of oil on shipboard, or for portable furnaces such as those for rivet heating, etc., but these factors are of less consequence in land power stations, where the chief factor is the primary fuel cost. It is impossible to lay down a hard and fast rule on this matter of fuel cost, but some idea of the relative values at varying prices would be of considerable value, though I readily admit that each problem as it arises should have individual consideration.

In this country the natural fuel is coal, and under existing conditions practically all our liquid fuels are imported. Further developments in the distillation of coal, shale, or other oil-producing medium may alter that condition eventually, but, taking things as they are, I am inclined to think that, in the majority of cases for land work, coal, or gas generated from coal, is the more economical proposition.

In the comparative weekly costs of Babcock & Wilcox boilers given in the paper, the cost of coal and ash handling seems excessively high. Is it usual to pay as high a wage for emptying wagons or loading ashes as for tending fires, and the other duties of a stoker? Also, if three men can attend the latter are five men necessary for the former, especially where plant for conveying the coal and ash is evidently installed?

I was interested to learn that a mixture of coal and oil firing has been successfully tackled, as my experience of mixed fuel has not been a happy one. In one instance the steam generated in a mixed coal and oil test was actually less than if an equal thermal value of either fuel had been burnt separately. I have also tried in a blast-furnace plant to burn coal and gas simultaneously in one boiler furnace, but never found this satisfactory. To burn oil as an auxiliary in a plant normally coal fired, to meet the demand of peak loads, I certainly consider it better to keep a separate boiler under light steaming conditions for the oil fuel, capable of being rapidly

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brought into use for the peak period. In many cases, however, I think it would be found that a system such as Dr. Ruths' accumulator would be an even better solution.

Is the application of oil fuel as auxiliary to blast-furnace gas, in the manner described in the paper, the best means of achieving this purpose? Would it not be better to enrich the gas by carburation in the manner adopted in water-gas plants rather than by introducing the oil in separate burners? The control of this could be made entirely automatic by instruments actuated either by the pressure or temperature of the steam.

I note that in one of the boiler tests quoted, Mr. Baillie says the water evaporated was measured by meter, and that Mr. Butler makes some disparaging remarks on the use of meters for this purpose. I am afraid that Mr. Butler has been unfortunate in his choice of a meter. No doubt there are unreliable meters on the market, but I can assure him that a positive water meter can be relied on to give reasonably accurate results. To make my assertion clear, I should say that the definition of a positive meter is one which provides a space to be filled and emptied periodically. Such meters have cylinders of a given diameter, and pistons with a predetermined stroke. These pistons are provided with elastic cups, the pressure on which keeps them tight against the walls of the cylinders. It follows, therefore, that so long as the correct stroke of the pistons is maintained and the piston packings remain perfect, every drop of water entering the meter is measured. Many meters of well-known make have been kept in this condition for over 25 years at a cost of 1s. 4d. per annum on cold water, though, of course, the conditions in handling hot feed-water are more severe. Such meters on test at the makers' works come within 2 per cent. of correct registration at a dribbling flow of from two to five gallons per hour, so that on service, at full capacity, they cannot be far short of 100 per cent. accuracy.

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Mr. C. H. Wright.

Mr. C. H. WRIGHT (Member): Mechanical engineers have sometimes expressed surprise at the rapid development of the application of electricity to mechanical work. I believe that the true reason for this rapid development is that electrical energy is susceptible to ready, rapid, and accurate measurement. When electrical engineers began applying electrical energy to motive-power work, they had the great advantage of starting with a set of units of measurement and with accurate measuring instruments.

The application of oil fuel also owes much of its success and rapid growth to the relative ease with which it can be measured as compared with solid fuel like coal. If the engineer running a plant has some kind of measuring instrument constantly before him, indicating the quantity of fuel consumed from hour to hour, he will at once notice any serious discrepancy or departure from the normal, and thus be in a position to seek the cause of any abnormal consumption. Economy in oil consumption is thereby promoted. In electric power stations, meters are often fitted for measuring solid fuel, but these do not appear to be fitted largely on board ship.

In the course of my business I have had to watch a good many consumption trials on board ship and ashore, and have found that a tank gauge of simple character, fitted in connection with the settling or daily service tank, and scaled to read the weight of oil in this tank at all times, is of extreme convenience. Readings may be taken at regular intervals, and the consumption recorded, during the trial. On service, such simple apparatus is invaluable, because it is easy for the staff to log the consumptions per watch without having recourse to any sort of oil flow meter which has mechanical working parts and is liable to be deranged by any deposits from the oil as it flows through. It would be interesting if Mr. Baillie could indicate the savings made possible by the reduction of the stokehold staff on board ship where oil fuel is burned instead of coal.

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Mr. C. H. Wright.

I believe that, about 20 years ago, Mr. Holden fitted some locomotives on the Great Eastern Railway with oil-fuel burning apparatus, and if Mr. Baillie has any knowledge of what was then done it would be interesting to hear from him whether the results of the change from coal to oil, in that instance, were successful, and if not, what was the reason. Probably in the case of railway work in South America and other countries, to which Mr. Baillie refers, it is a matter of supply, oil fuel being obtainable in the country itself.

With respect to the general use of oil, particularly by relatively small users, the chief difficulty is the price and the uncertainty of its stability at reasonable figures. Some years ago I was connected with the burning of fuel oil on steam omnibuses in London and district, and, while kerosene was at a fairly low price when bought in bulk, considerable success attended the work, but in the early years of the war the price rose so much that it became unprofitable to continue using it, and a good thing was spoiled. When the application of oil is being considered, particularly in fairly small plants ashore, the question of price and the possible variations in it is one which creates a good deal of nervousness.

Mr. A. J. Campbell (President): I was particularly struck with the carefulness of oil suppliers by one little sentence, in which Mr. Baillie says that in the case of the heavier oils which cannot be supplied to their customers, the oil is put in the cross-bunkers of their own steamers, where it is heated, and then, before being used, is put through another system of heating. Thus this heavy oil is used by the oil suppliers for their own purposes to their advantage. I understand this is done to prevent the accumulation of heavier oil at the refineries.

In the past, coal has been used with great prodigality, and has been neglected so far as taking the utmost out of it is concerned, but the oil companies are to be commended for

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Mr. A. J. Campbell.
having made such a complete effort to take the utmost out of the oil which they receive from mother earth.

The title of the paper is "The Commercial Application of Fuel Oil." I do not know if a ship's galley can be termed a commercial application, but that is one of the latest purposes to which fuel oil has been applied, and the cooks and others agree that their products are much better than they were when using uncertain coal, while the cleanliness of the galley is improved.

Mr. BAILLIE: In reply to Mr. Brown, I may say that high-pressure oil-burning systems have been used in the past not merely because high pressure was necessary for finely atomising fuel oil, but because the burner nozzles were not of such an efficient design as those in use to-day, which allow a lower oil pressure to be used to give as good a degree of atomisation as when using high pressure on the less efficient nozzles. Again, the modern method of steam-jet oil burning is to use a steam pressure of from 25 to 40 lbs. per square inch for jetting purposes. Some years ago boiler-pressure steam was used, again because the steam-jet burners were not as efficient as they are to-day. These efficient burners allow for the same degree of atomisation as the old type, but use low-pressure steam.

It was also found that when using high-pressure steam the distance between the burner nozzle and the point of ignition was so great that between these two points there was quite a large portion of boiler heating surface which did not do any work at all, thereby varying the water evaporation per square foot of heating surface in the length of the boiler flue, which, of course, set up strains in the flue. This difficulty has been overcome by the application of low-pressure steam for jetting purposes.

With respect to the difference in operating temperature of the oil used in the American and British Navies, I suggest

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the reason for this is that the American Navy use heavy Mexican residual oils, whereas the British Navy use Mid-Continent and Texas residual oils, and the difference in viscosity between the Mexican and the Mid-Continent or Texas oils is such that the Mexican oil has to be heated to a higher degree than the others mentioned to obtain complete combustion.

Mr. McGibbon thinks the weekly labour cost of £15 for three men for stoking coal a very high rate for such labour. That was the ruling rate for labour of this class in the London area some four years ago.

Eng.-Capt. Onyon says: "The fact that the temperature of the oil has to be raised before burning it under boilers is one which gives an engineer much concern." I do not know of any oil, whether of mineral origin or otherwise, which can be burnt in a cold state under boilers. Fuel oils generally are raised above their flash-point before being introduced to the boiler furnaces, but the degree of rise of temperature does not depend on the flash-point, but on the viscosity of the oil. To obtain maximum efficiency, it is advisable, with all classes of petroleum oil, to raise the temperature to correspond to a viscosity of 150 seconds Redwood No. 1.

The method of using fuel oil as an auxiliary to coal on H.M.S. "Dreadnought" from 1906 to 1908 was far from being an effective one. The only method of burning fuel oil as an auxiliary to coal is to burn it along with the coal, not after the coal has made such a heavy deposit on the fire-bars that no further consumption of coal can take place. Under such conditions it is almost as impossible to burn fuel oil effectively as it is impossible to burn coal at all, as it is necessary in all cases to draw the necessary quantity of air for combustion through the fire-bars, and if they no longer act as such, but as a blank surface, combustion of either coal or oil is impossible.

Referring to Mr. Jones' remarks, the reason why the steam-

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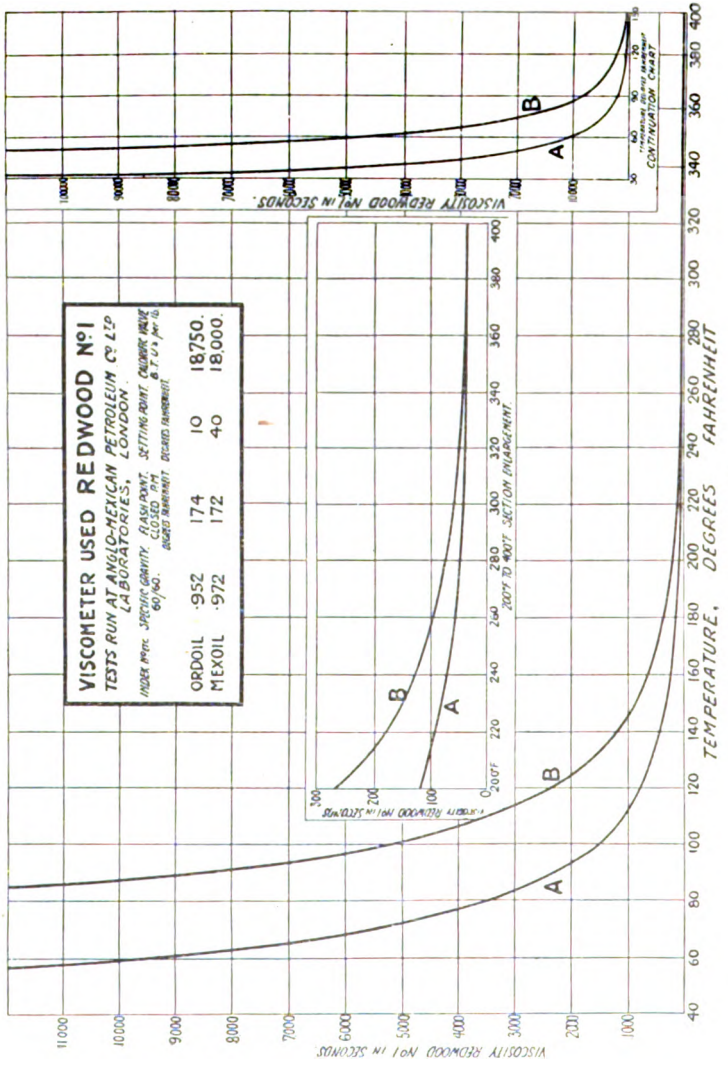
VISCOMETER USED REDWOOD Nº I
TESTS RUN AT ANGLO-MEXICAN PETROLEUM Cº LTD LABORATORIES, LONDON
INDEX APPROX. SPECIFIC GRAVITY 60/60° FLASH POINT, CLOSED P.M. DEGREES FAHRENHEIT SETTING POINT, CHLORIDE METHOD B.T.U.'s PER LB. DEGREES FAHRENHEIT
ORDOIL .952 174 10 18750.
MEXOIL .972 172 40 18,000.
A
B
VISCOSITY REDWOOD Nº1 IN SECONDS
TEMPERATURE, DEGREES FAHRENHEIT
200°F TO 400°F SECTION ENLARGEMENT.
INDUSTRIAL DIVISION MANCHESTER
CONVERSION CHART

Fig. 1.—Viscosity Curves.

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jet system of oil burning was introduced in the order given, namely, between the air-jet system and pressure-jet system, was merely from the historical point of view. The first-known oil burners were of the air-jet type, then came the steam-jet, and finally the pressure-jet system.

The figures quoted on the test of the oil-fired Lancashire boiler do not include economisers, as these were not fitted. I note with regret that Mr. Jones agrees with Eng.-Capt. Onyon on the question of auxiliary oil firing, as there are many land installations in this country which have benefited enormously from time to time, due to the fact that they were fitted with auxiliary oil firing. The auxiliary oil firing may or may not have been in use from day to day, but at times when large quantities of steam are required for two or three hours in the morning, and again for two or three hours in the evening, even if not required regularly week in and week out, the process work has been maintained at 100 per cent., whereas without auxiliary oil firing that rate would have been materially decreased.

Mr. Riddlesworth wishes to know what the comparison of 2·5 to 1 in favour of oil over coke for central heating means. It is calculated on a tonnage basis, and not on a monetary basis. Again, the cost of handling oil on American railways at the time when the information was obtained was ·03 cent per ton, and I cannot agree that even in this country, with the most inadequate methods of coal handling, the cost would ever approach 5s. per ton.

My experience of the use of town's gas for rivet-heating furnaces is that the time taken on these furnaces to heat a certain size of rivet is almost twice the time taken on an oil-fired rivet-heating furnace, and, furthermore, the cost of gas firing is prohibitive.

Mr. Butler alludes to the thermal efficiencies of the three different oil-burning systems quoted in the paper. These efficiencies were the relative limiting efficiencies over all of the

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Mr. A. F. Baillie.
steam-raising plants in question, and were test figures. Naturally an engineer would quote the highest test figure obtained rather than an average working figure. I cannot understand why Mr. Butler states that it is hardly fair to make a comparison with an oil-fired boiler by taking the efficiencies obtained from a coal-fired boiler simply on one test, and making deductions therefrom. The comparative tests shown on pages 203 to 205 were made to ascertain if the steam generation of the factory could be more efficiently run on oil fuel as against coal, taking everything, including the fuel bills, into consideration. That being the case, the comparative tests were carried out with only one object in view, namely, economy, and I cannot see any unfairness in comparing the results obtained.

With reference to the capital cost of steam-raising plant for a battery of four Babcock & Wilcox boilers, the figures of £3,000 and £1,300 were the costs of the apparatus for handling the coal and oil respectively, the figure of £8,000 being the cost of the boilers themselves, whether on coal or oil, not including any handling apparatus.

I do not agree that 16 lbs. of water from and at 212 degrees F. per i.h.p. per hour is an excessive figure for a large slow-running quadruple-expansion engine, as there were quite a large number of auxiliaries, many more than perhaps Mr. Butler is reckoning on; the case cited is not that of an ordinary tramp steamer. As to the question of the accuracy of measuring feed-water by means of meters, I cannot give a more enlightened reply to this question than refer him to Mr. Baird's remarks on this subject in the discussion of the paper.

The statement made by Mr. Bonn that the oil temperatures shown on pages 204 and 210 are meaningless is quite correct, for without knowing the viscosity of the oils at a given temperature, the viscosity of the oils mentioned at the temperatures given could not be stated. In Fig. 1 are shown two curves, A for Mexican Ordoil and B for Mex Oil. A refers

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to the oil used on page 204, and B to the oil used on page 210. Crude oils, whether "topped" or "untopped," are never used as bunkers.

Mr. Baird is anxious to know at what cost ratio oil becomes a more economical proposition than coal. The following figures give a general idea of the parity value of oil to coal for steam raising on various kinds of process work:—

	Coal.	Oil.	
Water-tube boilers - - -	1·42/2·02	1	- Pressure-jet system.
„ „ „ - - -	1·39/1·91	1	- Steam-jet system.
Lancashire boilers - - -	1·55/2·11	1	- Pressure-jet system.
„ „ - - -	1·46/2·00	1	- Steam-jet system.
Locomotive boilers - - -	1·46/2·00	1	- Steam-jet type burners.
Marine boilers - - -	1·55/2·11	1	- Pressure-jet system.
Billet-heating furnaces - -	6	1	- Air-jet system.
Brass and aluminium melting -	2	1	- „ „
Rivet, bolt, and nut-making -	6	1	- „ „

Mr. Baird is inclined to think that in the majority of cases for land work, coal, or gas generated from coal, is the more economical proposition. I cannot agree that gas generated from coal is under any consideration an economical proposition. In the comparative weekly costs of a battery of four Babcock & Wilcox boilers, the men emptying wagons and handling ashes were employed on the same monetary terms as the stokers. It was found necessary when running on coal to employ five men extra, whose duties were coal and ash handling, apart from stoking duties, and, as mechanical stokers were used when running on coal, it should be noted that the same number of men were used when running on oil solely for stoking purposes.

With reference to the application of oil fuel as auxiliary to blast-furnace gas, as described in the paper, the plant to overcome the low calorific gas troubles was so simple, and the method so effective, that I do not think for one moment that the iron companies would consider the question of enriching blast-furnace gas by carburation, as the application is only

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Mr. A. F. Baillie.

intermittent, and the overall cost of plant for this purpose would be in excess of any benefits derived therefrom.

In reply to Mr. Wright, I may say that the number of firemen and trimmers on the "Mauretania" was reduced from 322 to 84 when the vessel was converted from coal to oil. Again, on a voyage of an American-Hawaiian steamship from New York to Pacific Coast ports, Hawaiian Island ports, and returning by Philadelphia—via the Straits of Magellan out and home—the time for the round trip on coal was 186 days, as compared with 161 days when using oil, and the following savings were effected:—

Saved in victualling and manning - - - - -		$4,813	
Increased earnings.	Freight earnings increased by 150 tons, East-bound - - - - - - - -	1,275	
	Disbursements at coaling ports - - -	1,000	
Total - - - - - - - -		$7,088	
25 days saved at $500 per day, nett - - - -		12,500	
Total saving per voyage - - - - - -		$19,588	or £4,010

With reference to the mention made of Mr. Holden, late chief mechanical engineer of the Great Eastern Railway Co., who many years ago successfully demonstrated that oil was a practical proposition for British railways, only an abundant supply of cheap coal at that time precluded an extensive adoption of liquid fuel.

I certainly agree with Mr. Campbell that the oil-fired ship's galley does come under the term of a "commercial application," and it might be of interest to state that oil-fired cooking ranges are gaining in popularity, and the majority of new steamers are so fitted. Oil is preferred as a fuel because of the entire absence of dust in the galley, and the accurate and easy control of oven temperatures. The low air-pressure system of burner is employed here, and the oil is fed by

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gravity from a head of from 10 to 12 feet. For a large oven, say 21 feet in length by 7 feet in breadth, it is necessary to have six burners, each consuming about $1\frac{1}{4}$ gallon of oil per hour. On a smaller oven, 8 feet by 2 feet 6 inches, only one burner was installed, using about 1 gallon per hour.

The following figures illustrate the superiority of oil over coal as a fuel. It will be noticed that the time taken to attain an oven temperature of 450 degrees F. is reduced from two hours in the case of coal to 1 hour 5 minutes with oil:—

OVEN 8 FEET LONG BY 2 FEET 6 INCHES BROAD.

	Coal.	·897 Oil.
Temperature of oven before lighting up	59 degrees F.	62 degrees F.
Weight of fuel used to raise oven to 450 degrees F.	28 lbs.	20 lbs.
Time taken to raise oven to 450 degrees F.	2 hours	1 hour 5 minutes.
Total weight of fuel used in 8 hours	110 lbs.	69 lbs.
Air pressure at burners	—	8-inch water gauge.

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THE ECONOMIC VALUE OF BUNKER COAL.

By Otto Kahrs,
Member of the Institution.

15th December, 1925.

Introduction.

It is well known by all coal consumers that the quality of coal and its value to the consumer vary greatly, and that even one and the same brand may vary considerably in quality. So far as shipping is concerned, these variations are much larger than is usually supposed. In modern practice, with large stationary power plants, coal is often bought per 10,000 calorific units, with certain modifications for ash and moisture. Such advanced practice has not yet been adopted for the purchase of bunker coal, for various reasons, the most important of which are:—

1. Lack of knowledge of the real conditions and the advantages possible with the purchase price based on the real value of bunker coal to the consumer.
2. Resistance on behalf of the collieries and the coal trade. This resistance can only be overcome by the co-operation of the shipowner and the time charterer.
3. The calorific value is not a sufficiently correct measure of the value of coal used for hand-stoked Scotch marine boilers under ordinary marine operating conditions, as the quality of the coal affects the boiler efficiency very considerably.

These relations have not yet been sufficiently investigated, but I have collected the published investigations which have come to my knowledge, and the results are given in extract

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in this paper. Based on these, the influence of quality of bunker coal may be tentatively approximated until further investigations are available.

The percentage of ash and volatile matter is of the greatest importance, while the quantity of fines (under $\frac{1}{8}$ inch), the influence of moisture, the draught available, and the difference between the maximum temperature of the burning coal-bed and the fusion point of the ash are of considerable consequence. The best method of expressing these influences is discussed, and two new terms are suggested, namely, boiler heating value and coal efficiency.

The boiler heating value would be the calorific value of the coal multiplied by the boiler efficiency with that coal. The coal efficiency would be the ratio of the boiler heating value of the coal to the boiler heating value of an assumed standard of coal, and would probably best be expressed as a percentage. The boiler heating value and, to a certain extent, the coal efficiency will certainly vary with the design, equipment, insulation, and condition of the boiler, the draught available, the skill of stoking, and the degree of forcing necessary; thus, although they are the correct measure of the value of the coal fired on that boiler, it will be necessary to adopt certain standards of design, operation, etc., to obtain general adoptable values. Fortunately the Scotch marine boiler has become a well-standardised unit, although skill of stoking, degree of forcing required, and draught available still vary considerably.

4. It is not only the quality of the bunkers which is of importance to economic value, but also the total weight, or in some cases volume, necessary for a certain trip, because the coal consumed, plus a suitable reserve, must be transported on the vessel, thus reducing the quantity of paying cargo carriable. It is shown that the influence of this factor is determined by adding the nett freight value per ton, *i.e.*, freight less all expenses charged per ton of freight, to the nett cost of the bunkers trimmed on board, and that the real value

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of bunkers to the consumer is the heat utilised by the boiler per ton of coal, divided by the cost trimmed in bunkers, plus the nett freight value, both per ton.

That bunkers vary very considerably in heating value and in behaviour on the fire has been the experience of all users since steamships became common carriers on the seas. Nevertheless, bunkers are practically exclusively bought on trade names, often of the most vague type, such as "Welsh steam" or "North-East Coast bunker." And even in the best cases, where bought direct from the collieries or with colliery certificates, trade names do not give any knowledge as to the real value of the commodity paid for. The reasons are several.

1. The heating value of the clean coal seam may vary somewhat, say five per cent. greater or less, and sometimes shows consistent variations between the top and bottom of a seam or eastern and western part of a field.

2. Clean seams are getting more and more rare as the old seams become exhausted, and the separation of the partings in the mine is often difficult, while the care applied varies considerably. As the inferior seams are started, a certain slow but continuous depreciation of quality will result, although, of course, the progress of technical knowledge in the preparation and dressing of coal may be expected to counterbalance this to some extent.

3. Care and time are also required for the separation of impurities from the floor or roof of the seam.

Neither partings nor parts of the floor or roof are coal; the hewer has the obligation to separate them, and is not entitled to any pay for such impurities, and the collieries are supposed to inspect all coal delivered by the hewer. Under the conditions existing during the war this regulation was apparently more or less relaxed, and permission was given at some places to use shovels instead of coal forks for the loading of tubs. This is thought to have had a good deal to do with the decrease

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of coal quality experienced at that time, and the effects of the change are still painfully felt. The great scarcity of skilled miners in Britain during the war should also be remembered, and labour would not be present-day labour if it did not endeavour to take advantage of the situation as much as possible. If impurities which are dug out with the coal or accidentally loosened from the face are paid for as coal, instead of being separated, then the results to the user must be bad. Unfortunately, it may be a long and difficult task to return to proper conditions.

4. Many collieries are working seams of varying properties. The products are often mixed purposely or accidentally, and cause considerable variations in quality owing to bad mixing or subsequent separation during storage or handling.

5. The screening and dressing arrangements at the pit are frequently not too modern. Hand picking, the method mostly used in Great Britain, is dependent exclusively upon the skill and attention of the pickers; the attention paid is often of a most variable nature, and seriously influences the quality of the products. Coal washing is in a more favourable position in this respect, but the increase of moisture in the finished products too frequently outbalances the advantages gained by the reduction of ash, and satisfactory drying of the washed coal is apparently no easy problem to solve.

6. Coal stored in heaps or bunkers may partly grade itself, and when afterwards shipped may reveal considerable variations in quality, especially with unscreened coal, for the fines always show higher ash contents and lower heat values than the larger coal. Further, they are apt to contain much more than the average percentage of the impurities referred to in sections 2 and 3.

The result is considerable variations in the same brand, and how large these are I fear most of the shipping interests are not aware.

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Table I.

Results of the Regular Sampling and Analysing of Coal Deliveries.

	A	B	C	D
	Min. Max. Average Per Cent.	Min. Max. Average Per Cent.	Min. Max. Average Per Cent.	Min. Max. Average Per Cent.
Total moisture	1·5 2·67 3·8	1·85 2·49 3·35	1·9 2·31 3·09	1·01 1·55 2·81
Volatile matter	29·5 31·6 33·8	27·62 30·34 32·64	24·7 27·75 29·36	24·47 26·97 30·35
Fixed carbon, free from ash	52·7 57·46 60·7	56·28 57·94 59·63	58·49 61·26 64·6	55·9 61·30 64·51
Ash	6·4 8·27 11·5	7·07 9·23 11·66	6·88 8·68 10·52	7·91 10·18 13·28
Small coal through ½ in. square mesh	25·3 36 51·1	29·69 44 53·3	36·14 46 68·09	33·1 45 54·73
Large coal	36·7 60 69·1	42·97 52 67·25	30·24 50 61·33	41·66 51 61·05
Dirt in large coal, hand-picked from the large portion of samples	4·1 5·9 8·5	4·15 6 8·93	3·6 5·6 7·35	3·55 6·2 9·08
Total quantity in tons (about 1 sample per 1,000 tons)	40,000	40,000	20,000	50,000

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May I, as a proof of this, refer to Table I, compiled from figures given in a paper by Mr. G. M. Gill,* relative to the results of the regular sampling and analysing of deliveries by the South Metropolitan Gas Co., London, during part of 1921. This company is perhaps one of the largest single coal consumers in the world, using about $1\frac{3}{4}$ million tons annually, and, therefore, a customer that might expect to receive every consideration from the collieries. In view of this company's experience, what may not be the treatment received by an ordinary bunker customer?

Important also are the figures stated by Mr. M. Jockel,† who in the discussion on this paper gave the results of regular tests of the coal fired by a large London boiler plant during 1922, excluding the period of the coal strike, and these are reproduced in Table II.

TABLE II.

VARIATION IN COAL QUALITY DURING 1921.

	Minimum. Per Cent.	Maximum. Per Cent.	Average. Per Cent.
Total moisture - - -	2·7	19·6	11·3
Ash in dry fuel - - -	5·6	32·2	16·5
Volatile matter in dry fuel -	23	32	24·2
Fixed carbon in dry fuel - -	52	69·9	59·2

As coal, even of the same brand from the same colliery, varies in quality, it is not really fair to charge a regular price per ton for it, and it is undesirable that the consumer should continue to buy on the old method. The price should be proportionate to the heat transferable in steam under operating conditions of the boiler. This fact has long been

* "Engineers and Chemists: the Co-operation of the Engineer and Chemist in the Control of Plants and Processes." Engineering, 13th January, 1922, p. 57.

† Engineering. 13th January, 1922, p. 52.

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appreciated by those engaged in advanced stationary engine practice, and especially in the U.S.A., where more scientific methods have long been practised. These methods are usually based on paying for the coal on its lower nett calorific value, frequently with certain price modifications for varying ash and moisture contents, and I beg to refer to the literature quoted for further information.* The U.S. Government, through the Bureau of Mines, is probably the largest buyer on this system, which, more or less modified, is adopted by many of the large steam-driven electric-power stations of the U.S.A. In Europe also it is widely practised, as, for instance, by the Swiss State Railways, the Swiss Association of Boiler Owners, several Swedish consumers,† and in England, where there is an important agreement between the principal London firms of coal contractors and the Associated Municipal Engineers of Greater London.‡

It is true that many of these methods had to be given up temporarily owing to war-time conditions, and that certain difficulties have prevented a return to old arrangements, but progress cannot be continuously stopped, and such an obviously fair thing as to pay for what is really received cannot be prevented from winning through in the long run.

As far as I know, scientific methods of coal buying have not yet been practised for bunkers. What are the reasons?

1. Shipowners and marine engineers are inclined to be very conservative. They are reluctant to consider suggested improvements, and ready to doubt their value and discount any possible savings. Concisely stated, they are to a very large extent neither aware of the gravity of the situation nor of the economies to be gained.

* See Bibliography, p. 293.

† G. Dilner, Om Stenkol och Stenkolsinköp, Stockholm, 1914, pp. 50-65.

‡ The Iron and Coal Trades Review, 28th March, 1913, p. 499, and Brame, Fuel, London, 1914.

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2. The conditions of tramp shipping generally enforce the buying of relatively small quantities of coal at various coal depots all round the world. Under such conditions a single tramp owner will not be able to secure coal on a scientific basis except through the concerted action of a large and influential body of owners and time charterers, who in this respect may be considered to be the managing operators.

But these reasons do not apply to the U.S. Naval authorities, who do not buy coal on any basis of calorific value, in spite of the fact that they have been repeatedly urged* to do so.

The crux of the situation lies in the fact that, although the nett calorific value may be quite a suitable measure for the boiler value of the coal when fired in modern stationary plants with ample combustion spaces and mechanical stokers, etc., it is *not a sufficient measure alone* for judging the real value of bunkers fired under average marine conditions, namely, indifferent stoking, Scotch boilers with a very limited size of combustion space, and frequently insufficient draught. This means that an effort must be made to determine the true value of bunker coal for the shipowner or time charterer, and this depends on factors of two different groups, namely, factors influencing the boiler efficiency, and factors arising from the

* J. O. Richardson, in his article "Coal for the Navy," in the Journal of the American Society of Naval Engineers, vol. xxvii, 1915, p. 339, states :— "Theoretically this (purchase on a B.Th.U. basis) is an ideal way of purchasing coal, but, practically, it is very unsatisfactory, because it frequently happens that coal which, in a laboratory test, would be rated very high on a B.Th. U. basis, gives very poor results when burned in the furnace of marine boilers, and conversely. In fact, one of the very best steaming coals on the market (U.S.A.), and one which is largely used by sea-going steamers, would be barred from competition because it is lower in B.Th.U's. than other first-class coals, and would, therefore, be forced to accept a lower price than such coals or abandon the Navy trade, which it probably would. This coal—George's Creek—has long been recognised by marine engineers as one of the most satisfactory on the market."

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fact that bunkers have to be carried on board the ship, thus reducing the quantity of cargo (in the widest sense) carriable.

FACTORS INFLUENCING BOILER EFFICIENCY.

The ideal combustion conditions in the calorimetric bomb—very large excess of pure oxygen under high pressure and the cooling down of the combustion products to practically the starting temperature—are, of course, impossible to reproduce in a boiler, and a certain consideration is already made through the usual European practice of calculating boiler efficiencies with a recalculated lower heating value—the so-called "lower" or "nett" calorific value.*

The main factor influencing boiler efficiency is the *amount of excess air* necessary to obtain maximum efficiency. With hand-fired boilers this is, of course, a continuously varying quantity, as shown by Fig. 1.† It reaches its maximum shortly after the closing of the fire-door after fresh coal has been added, and its minimum just before or during the next firing. The air actually entering is, on the other hand, usually a more or less constant quantity, varying rather in the opposite direction, and increasing as the layer of burning coal becomes thinner, especially if holes are formed in the layer. This is counterbalanced to some extent, as far as total air quantity is concerned, by clinkering of the fire, which, how-

* To ascertain this item it seems to me that it would be best to recalculate the heating value of the coal with the gases cooled down to the temperature of the saturated steam produced, this being the theoretical cooling limit of any steam boiler proper, or, as this would complicate calculations, eventually to a definite temperature, say, 200 degrees C., or 400 degrees F., and not to consider only part of the combustion products—the latent heat of the H_2O—and that in a totally arbitrary manner. After this was written, I found in "Power," 6th November, 1923, p. 737, that G. D. Roselli, in "Cheap Steam," September, 1923, has advanced the same idea, proposing 100 degrees C., 212 degrees F., which is much too low a figure in my opinion.

† Fig. 1. Gensch, Berechnung, Entwurf und Betrieb Rationeller Kesselanlagen, Berlin, 1913, Fig. 18, p. 66.

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ever, owing to the increased inequality of air distribution, again increases the total quantity necessary.

The quality of the coal here enters into the question in several ways.

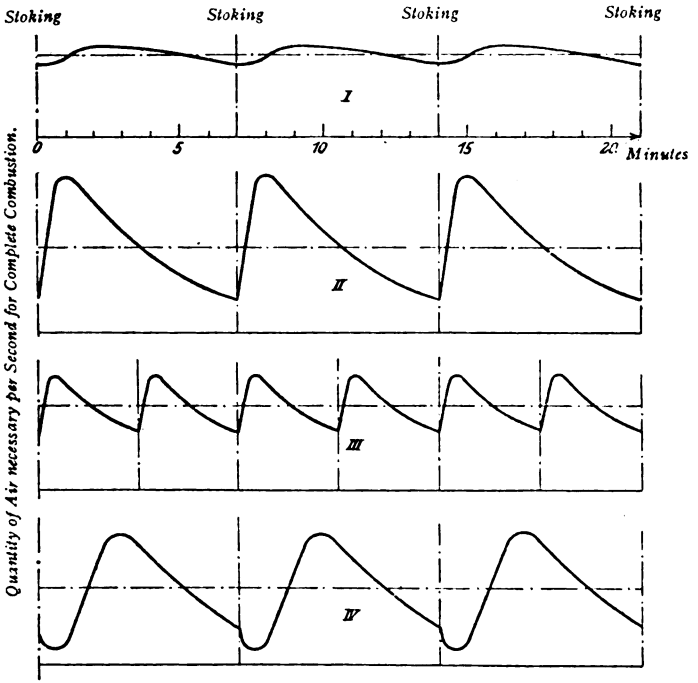

Fig. 1.

I. Air necessary with anthracite.
II. Air necessary with coal containing much gas.
III. Air necessary with coal containing much gas, and frequent stoking.
IV. Amount of heat generated for the boiler when firing according to II.

1. Quantity and Quality of Volatile Matter.

Whereas the combustion of "fixed carbon" to a large extent takes place in the fuel-bed, and is completed within a very short distance from the fuel-bed surface, practically the whole of the complex combustion processes of the volatile

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matter from ordinary grates have to take place in the combustion space. Any combustible left unconsumed, when the gases reach the tubes, must be considered as lost, because the temperature then immediately becomes too low and the conditions too unfavourable for useful combustion, although it may start burning again in the funnel, as the flaming funnel tops of strongly-forced naval vessels amply prove.

The time necessary to secure complete combustion depends upon:—

(a) The concentration of oxygen at the spot of reaction according to the law of mass action. This is, of course, a continuously decreasing value as the combustion proceeds, and for the case under consideration varies with—

1. The amount of excess air admitted.
2. The equality of its distribution over the grate.
3. The perfection of mixing in the combustion space.

(b) The temperature during combustion, which, of course, depends upon the heat developed and the heat absorbed. Thus, besides point 1 above, also on—

4. The rate of heat developed per unit grate area per hour.
5. The ratio of heat absorption of the heating surfaces.
6. The amount of radiated heat absorbed by the combustion products.
7. The amount of heat radiated by the burning gases.

(c) The quantity and composition of the fuel to be consumed. In addition to point 4 above, this also depends on—

8. The composition of the volatile matter.

(d) The time used for heating the green coal is certainly of considerable importance as well, and with the restricted combustion space available in the Scotch boiler, in addition

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to the factors above mentioned, the following factors will count:—

9. The amount of fresh coal fired at each stoking.
10. The temperature of the fuel bed and furnace.
11. The size of the coal fired.
12. The method of firing.

And there may be still other factors to be reckoned with.

The situation is further complicated owing to the fact that the amount of volatile matter generated per second varies all the time between any two firings. The present state of our knowledge does not permit of tracing the influences of the before-mentioned factors separately, and they are so interdependent that it is probably impossible to do so. Fortunately a great number may be considered to be practically constant for a given boiler, and largely so for a type that has become as nearly uniform as the Scotch marine boiler.

Up till now the time necessary to secure complete combustion has not been discussed, but actually the time available may be regarded as the average time taken by the combustion products to travel from the fuel-bed surface to the rear tube-plate, and is constant for a given quantity of fuel burnt with a given percentage of excess air. In the mercantile marine the power required may be taken as constant.

Therefore, the variable factor is not the time necessary for complete combustion, but the amount of incomplete combustion for a given percentage of excess air, or the amount of excess air necessary to avoid incomplete combustion; or rather the sum of the losses due to incomplete combustion and the temperature of the combustion products entering the funnel base when they are a minimum. For a certain boiler and furnace, this will mainly depend upon—

The quantity of coal fired each time and the stoking methods used.

The percentage of volatile matter in the coal.

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The quality of the volatile matter. Unfortunately, there are no suitable laboratory methods known at present to measure this factor in a practically useful manner.

The condition of the fire—temperature and air resistance, holes, levelness, clinker, etc.

The output required by the boiler, which may be considered to remain constant for any mercantile vessel.

The efficiency of the heating surfaces.

The amount of air actually supplied is a relatively constant quantity, generally increasing as the layer of coal burns thinner. There will thus usually be too little air during the first period, quickly changing to a considerable excess during the last $\frac{2}{3}$ or $\frac{3}{4}$ of the interval between any two firings. A remarkable proof of this may be had by watching the funnel top of a steamer. Shortly after a furnace has been fired, black smoke appears in considerable quantities, and soon reaches its greatest density; it quickly becomes lighter and lighter, until a smokeless condition is to all intents and purposes reached. The result is that, in the beginning, there will usually be a considerable loss due to incomplete combustion, followed by a gradually increasing loss in the funnel gases due to excess air, and increased leaving temperature owing to the increasing quantity of excess air.

2. Quantity of the Ash and Behaviour on the Fire.

Of these factors the latter is the more important, and depends upon the fusion point, *i.e.*, the softening temperature of the ash. The fusion point again depends upon the chemical composition of the ash, and on the kind of atmosphere, it being considerably lower in a reducing than in an oxydising one.

This statement is possibly not the whole truth, as caking of the coal, which has a considerable influence on its behaviour in the fire, is dependent upon the composition of the volatile

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portion of the coal; but little if anything is definitely known concerning the causes, more than that it is due to the tarry components of the coal, although the results are well known. It is known, however, that when the ash becomes soft it forms into clinker, which plugs the air channels in the fire-bed, reduces or stops the air admission, and, as it occurs locally to begin with, increases the inequality of air admission, thus decreasing the excess of air at some places of the grate and increasing the losses already referred to. There will, accordingly, be either greater losses due to local increases of incomplete combustion, or the amount of excess air must be increased to counteract the effects of clinker, and thus the funnel losses become larger.

The behaviour of clinker, however, varies, and it is possible that the fusion point and fuel-bed temperature alone are not sufficient to explain these variations. Sometimes clinker will spread quickly into large, soft cakes, which must be broken up to maintain combustion. These cakes of clinker are inclined to stick very hard to the furnace grates, and are difficult to remove, the result being frequent renewal of fire-bars. In other cases the clinker becomes hard, and is not really troublesome so long as the fire-bed is left undisturbed. The presence of hard clinker requires skilled stoking to avoid holes and thin places. If the ash melts completely, it is very trying on the life of fire-bars, etc. Highly fusible non-clinkering coals are, of course, the best, although some refuse will always form, and this ultimately has to be cleaned away.

Although clinkering of the fire decreases the excess of air during the burning out of the fixed carbon, and to some extent may counteract any harm done, yet the balance will, unfortunately, always be a considerable minus quantity. Soft or viscous ash envelops combustible particles, thereby preventing the admission of oxygen, which also causes a further heat loss owing to unconsumed combustible matter. The work of the stokers is increased, and during the cleaning periods the

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excess of air rises out of all proportion, CO_2 percentages of 4, 3, and even 2 occurring, which means both a considerable heat loss and a falling off of steam pressure and speed of the vessel when cleaning fires. This has become so familiar to seafaring people as to be considered practically unavoidable, although it need not be. Finally, the heat in the hot refuse removed is, of course, also lost.

3. Amount and Size of Fines.

With unscreened coals the term "fines" is usually applied to all particles passing through a 3·2 mm. ($\frac{1}{8}$ inch) round-holed sieve, and it is often used for screened coals as well, where, strictly speaking, all parts smaller than the minimum mesh of the screen might be considered as fines.

Experience shows that small coal, say perhaps below 25 or 20 mm. (1 inch or $\frac{3}{4}$ inch), shows a higher ash content,* and, accordingly, a lower heating value than the larger sizes. This becomes more and more pronounced as sizes further decrease, and as soon as it is smaller than, say, 12 mm. ($\frac{1}{2}$ inch), it is very difficult to burn efficiently on ordinary grates, and, therefore, fetches lower prices. It is thus explainable why the collieries prefer to include their fines with the bunker coal, and that the screening arrangements are perhaps not always ideal. This feature, however, has lost most of its importance since the introduction of practical coal-dust firing systems, and sharp screening should now be insisted upon, especially where the draught is weak or boilers are on the small side, because the fines increase the resistance of the fuel-bed very considerably. Thus 30 per cent. of fines passing $\frac{1}{8}$-inch holes will increase the fuel-bed resistance by 50 per cent., and, according to Worker and Peebles, 40 per cent. of fines will reduce the quantity burnt per unit of grate area by 40 per cent.

* Worker and Peebles, Mechanical Stokers, New York, 1922, pp. 107 and 139.

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A considerable portion of fines is due to breakage during the transport and handling of coal, and coal obtained from bunker depots, therefore, usually shows a greater quantity of fines than that obtained at the export harbour, but the fines thus produced have, of course, the same ash content, and the penalty for such increase should, therefore, be fixed lower. The amount varies greatly with the friability of the coal (many of the best coals are, unfortunately, rather fragile) and the methods of handling.

Losses of combustible matter are also caused by the refuse sifting through the grate, often to such an extent that artificial moistening is resorted to.* This so-called tempering of the coal is best done an hour or two before use. Combined with the ash, this refuse greatly influences the loss due to combustible matter in flying coke or dust.

4. The Influence of Moisture.

This is usually taken into consideration when determining the "nett" or "effective" calorific value as supplied, although the bomb determinations are always made on dry fuel.

Special attention should be given to the conditions to which the calorimetric bomb heating values are referred, such as "ash and moisture free," which is the ideal for the comparison of combustible† matter, "air dry," or "as received." Even in the last case, unless special precautions are taken, it is best to determine the "wetness," that is, the moisture content above the "air dry" condition, immediately at the sampling place. The moisture determined at the laboratory may be perceptibly different, and is usually less than that of the coal supplied.

* It is probable that such moistening also improves the combustion with certain coals.

† Not really combustible in the strict sense of the word, as N and O are included.

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The influence of the first three of these factors on boiler efficiency is affected by so many variables, depending upon the design of boiler and method of firing, and are so interdependent, that it is impossible to determine the effect of each.

Some of these variables are:—

(a) The design of the furnace and boilers, including—

Design and size of combustion chamber,
Length of flame path,
Mixing facilities,
Kind and strength of draught available,
Draught regulating arrangements,
Design of grate and fire bridge,
Arrangements for air above the grate,
Heat developed per unit grate area per hour, etc.; and

(b) Grade of stoking—

Quantity fired each time,
Methods used,
Regulation of draught,
Levelness of fires,
Avoidance of holes in the fire, etc.

It is thus evident that the influence of the quality of bunker coal on boiler efficiency is not constant, but varies considerably with the design of the plant and the conditions of operation. This is possibly one of the reasons why this important question has been given such little consideration up till now.

Generally speaking, however, mercantile marine installations are very similar, Scotch boilers with natural or Howden's forced draught being practically standard. Test results of the value of coals obtained on representative average Scotch

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boilers can, therefore, be applied to the large majority of mercantile vessels with satisfactory accuracy.

The size of the boilers on the average tramp and many passenger vessels is frequently on the small side—a pronounced example of small saving which becomes very expensive in the long run—and I would like to recommend not less than $3\frac{3}{4}$ square feet of heating surface per sea-going indicated horse-power for an ordinary triple-expansion plant. Cramping the heating surface is bad practice also from the point of view of running expenses.

As far as natural draught is concerned, however, the strength of draught available on various vessels varies considerably, from plenty in hand down to so weak a draught that steam can only be maintained with the most suitable grades of coal. This is a very important point, for some fuels, otherwise very good, are next to worthless with weak draught. Coke, for instance, will only give the usual marine ratings with a very strong artificial draught.

The best solution would, therefore, be systematically to investigate combustion conditions on marine boilers, including influence of size of combustion chamber and special boiler types, length and position of grates, fire-bridge conditions, influence of preheated air and of draught, etc., and the various grades of coal, including different firing methods and strengths of draughts.

It should thus be possible to obtain both reliable data on the relative values of various grades of coal under average and good firing conditions, and to secure most valuable data on the best proportions of boilers and methods of stoking, etc.*

I am absolutely convinced that such an investigation would prove the best investment for shipowners and time charterers

* A most interesting step in this direction has already been taken by the U.S.A. Shipping Board—cf. U.S. Bureau of Mines Bulletin 214, Tests of Marine Boilers, by Henry Kreisinger, John Blizard, A. R. Mumford, B. J. Cross, W. R. Argyle, and R. A. Sherman.

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at the present time, but the difficulties must not be underestimated, as otherwise the conclusions drawn may prove untrustworthy, and may then easily stop or seriously delay the progress of a thoroughly good and sound cause.

A few of the difficulties may be mentioned:—

1. As the coal tested may vary in quality, it may be very difficult to draw correct conclusions.

2. The question of the correct sampling of the coal, flue gases, and refuse must be given the very closest attention, and it is most difficult to obtain reliable average values. To a smaller degree, perhaps, there is also the difficulty of temperature measurement, which up till now has practically always given too low values owing to radiation influences.

3. The number of other sources of error in boiler tests is great, and it is not easy to keep these sufficiently constant to secure reliability concerning the influence of any variable under investigation or to solve the complexity of their interdependence. Therefore, if the greatest care is not exercised, misleading conclusions may be easily drawn.

The investigations should be made with boilers with full-sized furnaces, although boilers with two or even one furnace will do, and to reduce the errors the trials should at least be of 24 hours' duration each. The time required for such an investigation will, therefore, be very considerable, but the cost need not become excessive if the steam can be sold at a fair price; but it will, of course, be necessary for the purpose of the tests to keep the load practically constant day and night, and such a customer may be difficult to get. Many, if not most, of the determinations can be made by automatic registering instruments.

Until such test results are available, use can only be made of the results of investigations already recorded. Unfortunately such investigations are very scarce, and the few exist-

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ing have been carried out principally on water-tube boilers, usually mechanically stoked, and hardly any on Scotch boilers.

I now beg to draw attention to the investigations which have come to my knowledge.

1. Influence of Volatile Matter.

In this respect the only extensive tests on hand-fired boilers with internal furnaces, as Scotch, Cornish, and Lancashire boilers, are those made by the Swiss Society of Steam Boiler Owners, and published by Messrs. Constam and Schläpfer,* but, unfortunately they do not include any tests with the usual bunker coal grades. The results are given in Figs. 2 and 3, reproduced from the above publication, and Table III. Figs. 2 and 3 show that not only the quantity but also the quality of the volatile matter varies considerably. Thus the heating value of the coals tested varies between 7,400 and 8,500 cal./kg., 13,320 and 29,700 B.Th.U's./lbs.

This is perhaps easier to grasp when it is remembered that, according to Marks,† the incombustible part of volatile matter varies between 2 per cent. and, in extreme cases, 42 per cent. According to Fig. 3, the best results were obtained with coals containing from 15 to 23 per cent. of volatile matter; both larger and smaller contents gave inferior results. Insufficient draught will probably increase the figures given in many cases. Unfortunately, there is no real measure of the capacity for combustion of different grades of coal, which involves the question of ash and fines.

* The Influence of Volatile Matter on the Efficiency of Boilers with Internal Furnaces. Reports of Technical Researches, Part 103 (Über den Einfluss der flüchtigen Bestandteile fester Brennstoffe auf den Wirkunggrad von Kesselanlagen mit Innenfeuerung, Mitteilungen über Forschungsarbeiten auf dem Gebiete des Ingenieurwesens, Heft 103), Berlin 1911. [Various Annual Reports of the Swiss Society of Steam Boiler Owners, 1904-1907.] (Diverse Jahresberichte, u.s. 1904-1907, des Schweizerischen Vereins von Dampfkesselbesitzern.)

† Mechanical Engineer's Handbook, New York, 1st Ed. 1916, p. 595.

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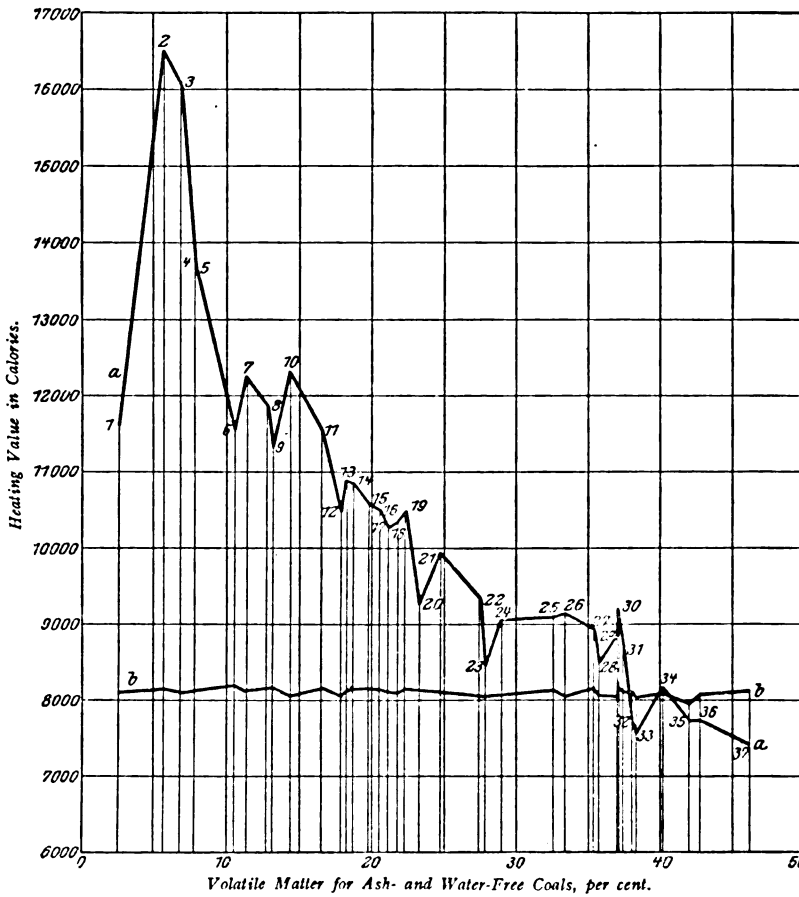

Fig. 2.

REFERENCES.

Curve *a*—Combustion Heat of one gram of Volatile Matter.
Curve *b*—Combustion Heat of one gram of Ash- and Water-Free Coke.

1. French anthracite de la Mure.
2. English anthracite.
3. Belgian anthracite Amercœur.
4. French anthracite.
5. Ruhr anthracite.
6. Anthracite Wiesche.
7. Lean coal from Flöz Mausegatt.
8. Half fat "Ess" coal from the mine Rosenblumendelle.
9. Belgian coal.
10. Half fat coal from the mine Rosenblumendelle.
11. Half fat coal "Sonnenschein."
12. Fat coal Grand Combe.
13. Fat coal from the mine Mansfeld.
14. Cardiff coal.
15. Fat coal from the mine Prosper.
16 to 18. Ruhr fat coal.
19. Fat coal Ronchamp.
20 to 22. Ruhr fat coal.
23. Ruhr flame coal.
24. Ruhr gas flame coal.
25 to 27. Saar coal Dudweiler.
28. Saar coal Klein-Rosseln.
29. English flame coal.
30. Saar coal Maybach.
31. Flame coal Mines de Bruay.
32. Saar flame coal Püttlingen.
33. Saar flame coal von der Heydt.
34. Saar coal Friedrichsthal.
35. Spanish coal.
36. Saar flame coal.
37. Saar coal La Houve.

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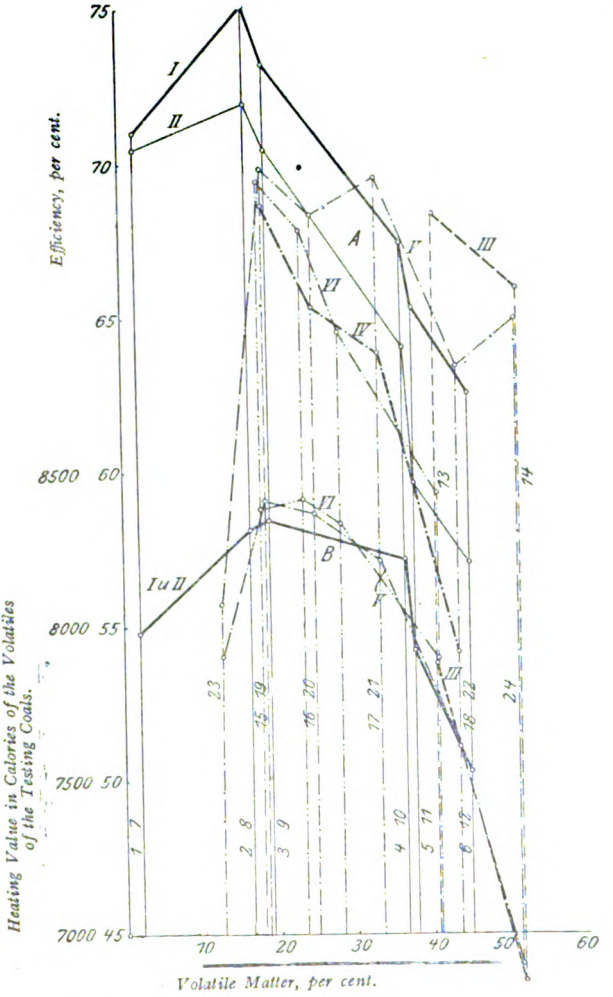

Fig. 3.

A.—Efficiencies of the evaporating experiments.
B.—Heating value of the volatiles of the tested coals.
Tests on the Scotch Marine Boiler: I—Normal speed, Gollscher grate. II—Increased speed, Gollscher grate.
Tests on the Lancashire Boiler: III—Ordinary grate. IV—Ordinary grate. V—Underfeed stoker.
Tests on the Cornish Boiler: VI—Ordinary grate.

ORDINATES.

1 and 7. Gas coke Luzern.
2 „ 8. Briquettes V.G.
3 „ 9 „ H.St.
4 „ 10. Saar coal Maybach.
5 „ 11. „ „ Friedrichsthal.
6 „ 12. „ „ La Houve.
13. „ „ Klein-Rosseln.
14. Brown coal Penzberg.
15 and 19. Briquettes R.
16 and 20. Ruhr coal, Deutscher Kaiser.
17 „ 21. „ „ Dalbusch.
18 „ 22. Saar coal Püttlingen.
23. Coke sand Winterthur.
24. Brown coal Penzberg.
25. Coal "Adler" M.A.
26. Ruhr coal Konstantin der Grosse.
27. „ „ Pluto.
28. Saar coal Merlenbach.

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That the combustion efficiency falls off with increasing amount of volatile matter has already been shown, but that there should be an optimum minimum value at first may look strange. The reason is that the draught available was not sufficient, and only a strong forced draught will permit of the relatively thick fire, which is necessary to obtain normal steam production with coke. With sufficient draught, however, very good results can be obtained, although careful stoking and level fires are essential, otherwise there may be a large loss due to flue dust, and arrangements for the admission of a sufficient quantity of air above the grates must be provided.*

For ordinary marine use coke is of little practical importance, however, owing to—

The large volume taken per ton. Eighty or more cubic feet of bunker space must be allowed for, instead of the 45 used as the standard for coal.

The great hardness causing increased wear of bunkers.

The usually relatively high cost of the heat content.

Increased ash content.

The last two reasons also frequently apply to low volatile coals.

It is not possible to express numerically the influence of volatile matter from the data at present available, and any formula or curves can only be reasonably accurate for certain conditions, especially with respect to skill in stoking. For average marine conditions a curve similar to Fig. 3, but somewhat flatter, might possibly be used until further data are accumulated.

Suitable arrangements for automatic variable air admission above the grates after firing, or, better still, combined with reduced air admission below the grates, will certainly greatly flatten the right-hand part of the curve, and the same will be the result of frequent skilled firing.

* Coke and Its Use in Relation to Smoke Prevention and Fuel Economy, E. W. J. Nicol, London, 1923.

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Summary of Results of Trials carried out for the Society of Steam Boiler Owners on Boiler Efficiency.

Ordinate No. Fig. 3.	Curve No. Fig. 3.	Boiler No.	Moisture as Fired. Per cent.	Nett Heating Value. Ash and Moisture Free.		Boiler Efficiency. Per cent.
				Cal.	B.Th.U's.	
1	I	1				
2			5·28	7,979	14,362	71·0
3			2·07	8,313	14,963	75·1
4			3·93	8,342	15,016	73·7
5			1·73	8,223	14,801	67·4
6			3·88	7,915	14,247	65·3
			5·42	7,525	13,545	62·5
7	II					
8			5·28	7,979	14,362	70·4
9			2·07	8,313	14,963	71·9
10			3·93	8,342	15,016	70·4
11			1·73	8,223	14,801	63·9
			3·88	7,915	14.247	59·6

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Fig. 4* shows the results of a series of careful tests on a hand-fired water-tube boiler of the Heine type, and Table IV contains results given by Kent.†

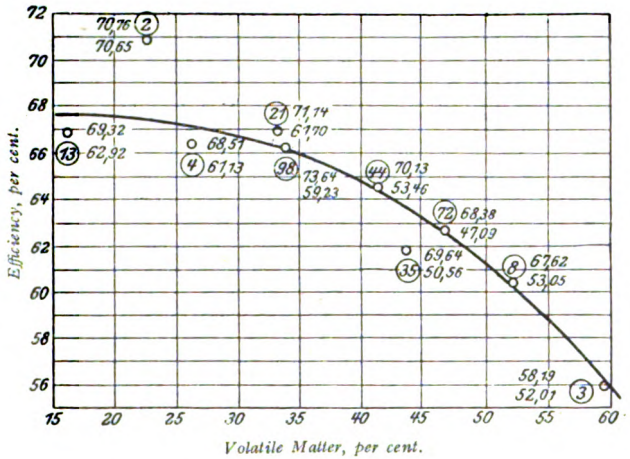

Fig. 4.

With mechanical stokers, now practically universally used in stationary-engine practice, the influence of volatile matter

TABLE IV.

Fixed Carbon Ratio, per cent.	97	80	68	60	54	50
Boiler Efficiency ,,	80	76	69	66	60	55
Reduction of Efficiency ,,	—	4	11	14	20	25
Reduction of Efficiency in percentage of the maximum -	—	5	13 7	17·5	25	31·2

is, within relatively wide limits, without much effect as long as the furnaces are suitable for the fuel to be burned.

* S. P. Breckenridge: A Study of Four Hundred Steaming Tests, U.S. Geological Bulletin 325. Washington 1907, Fig. 50.

† Mechanical Engineer's Handbook, New York, 10th Ed., 1923, p. 871.

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2. Influence of Ash.

A number of investigations have been made on the influence of ash, but none of them takes into consideration either the fusion temperature or the clinkering properties. They give only approximate averages, and further investigations are, therefore, highly desirable. Some of the results are reproduced in Table V.

Table V.

Ash, per cent.	0	10	20	30	35	40	50	
Anthracite* -	100	92	80	60	40	0	—	Relative values.
Bituminous†	0	12	23	45	—	70	100	Average loss of
Bituminous*	0	10	20	40	—	75	100	boiler efficiency.
Western* -	0	5	18	32	—	98	—	

Based on some 20 tests with the same boiler and stoker, G. Dilner‡ states that an increase of ash of 1 per cent. means a decrease in boiler efficiency of 1·05 per cent., or, say, 1 per cent. A. Bement§ observes that according to tests at the U.S. Fuel Testing Station, 1 per cent. increase of ash should represent 1·5 per cent. reduction in boiler efficiency, but, as far as I have been able to make out from the report on these tests, this value is too high for ordinary ranges of ash content, say from 4 to 15 per cent., unless there is very bad clinkering. He also quotes extensive tests by a very large electrical company on mechanically-stoked boilers,‖ where each per cent. excess of ash reduced the efficiency 1 per cent. This probably refers to an excess of ash above a certain standard percentage,

* G. A. Orrock: Some Phases of the Fuel Problem. Electrical World. 11th October, 1919, p. 802.

† Power, 4th April, 1922, p. 556.

‡ Om Stenkol och Stenkolsinköp. Stockholm, 1914, p. 48.

§ Power. 18th September, 1923, p. 449.

‖ Journal of the Western Society of Engineers, vol. xi, p. 554.

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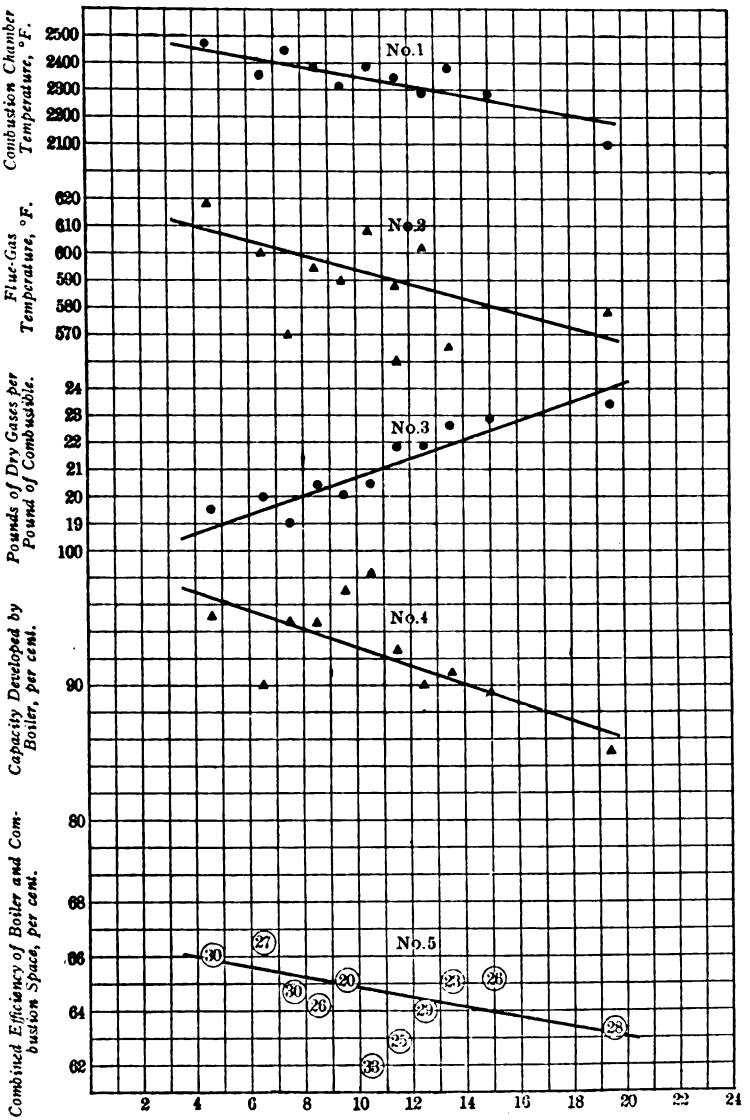

Fig. 5.

Curves showing the relation of the percentage of ash in coal to: Combustion-chamber temperature (No. 1); flue-gas temperature (No. 2); pounds of dry chimney gases per pound of combustible (No. 3); capacity developed by boiler (No. 4); combined efficiency of boiler and combustion space (No. 5).

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but, unfortunately, I have been unable to clear up this point, as I am not in possession of the original publication.

Figs. 5 to 7 are taken from the published survey of an investigation at the U.S.A. Fuel Testing Station,* which

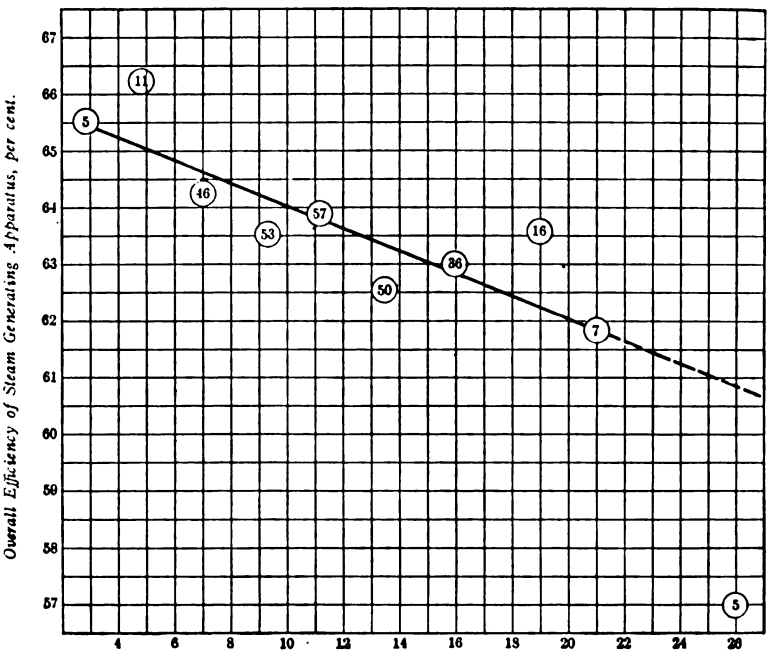

Fig. 6.

Curve showing the relation of the percentage of ash in dry coal to the overall efficiency of the steam generating apparatus.

states that the efficiency of the boiler and combustion space is only decreased by 1·5 to 2·5 per cent. for an increase of ash of from 6 to 17 per cent. for coals of practically the same composition from the same field in Illinois, and that this

* U.S.A. Bureau of Mines, Bulletin 23. Washington, 1912; Breckenridge, Kreisinger and Ray: Steaming Tests of Coals and Related Investigations, pp. 236 238.

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increase was practically exclusively due to the increased excess of air. But considering that the decrease of grate efficiency, which is quite considerable, has to be added to the above figure, I feel that this must be on the low side. It also seems that all the coals in question were reasonably non-clinkering under the conditions of test.

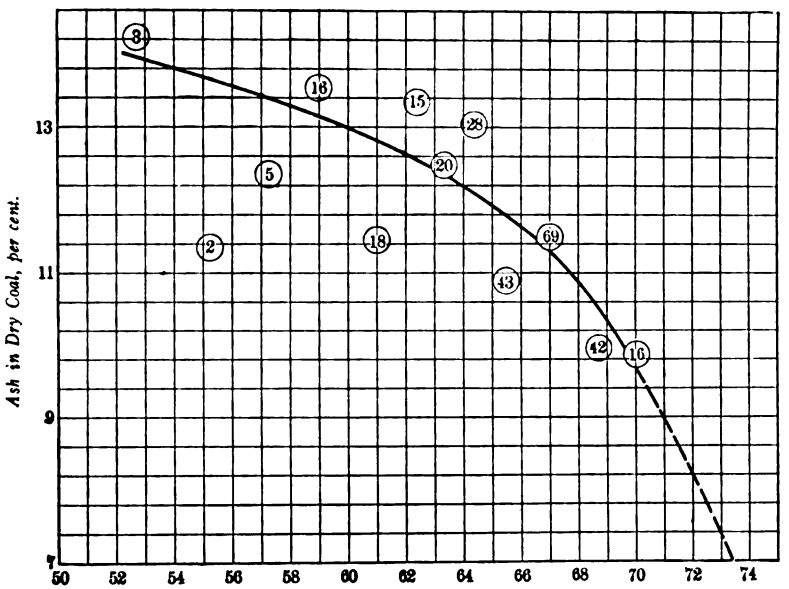

Fig. 7.

Curve showing the relation of the combined efficiency of the boiler and the combustion space to the percentage of ash in dry coal.

It will be seen that the difference of opinion is quite considerable, and this is only reasonable when the many important variables which influence the result are considered. Any curve such as those depicted in Figs. 5 to 7, or the values represented in Tables IV and V, can be approximately reduced to some suitable mathematical formula which may perhaps sometimes be more convenient for use. The objections to such a formula,

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unless it is based on the physical laws governing the case in question, are so important, however, that I have thought it best to refrain from making any such suggestions in this connection on the ground that—

Formulæ are apt to suggest a much more exact knowledge than at present exists.

They are apt to be used far beyond the limits for which they were designed.

3. Influence of Fines and Moisture.

No test data are available, as far as I know, regarding the influence of fines, but as a first approximation the loss may perhaps be taken as varying between ·25 and ·5 per cent., say ·3 per cent.; it would be more with forced draught, as the losses due to flying coke are then apt to be considerably higher, and the loss due to incomplete combustion is liable to become seriously increased.

Moisture is usually considered, to a certain extent, by using the "nett" or "effective" heating value, or it may not be considered at all, as is standard practice in the U.S.A., where it is considered as a separate loss in the boiler heat balance.

In my opinion, the ideal method of comparing boiler performances is the theoretical ideal boiler efficiency, based on an ideal boiler with no excess of air and a leaving temperature equal to the temperature of the saturated steam produced, and no other figures should be accepted as a base. The efficiency ratios reached, compared with this ideal boiler, will be a fair basis of comparison, just as steam engines or turbines are compared on the Rankine cycle.

Whatever method is used, coal ought to be paid for on a dry basis only, for it is combustible matter the buyer wants, and it is not fair that he should pay for water, possibly added by carelessness or during transport. In practice, special diffi-

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culties are met with in this respect, as it is very difficult to sample the moisture correctly.

The detrimental influence of high amounts of moisture becomes very great unless the coal is fired in special furnaces. In Germany brown coal with about 50 per cent. of moisture is fired regularly in many large power stations with efficiencies, on lower nett heating value, of between 70 and 75 per cent., but such arrangements are unsuitable for marine purposes, and coal with moisture above 13, or at the most 15 per cent., should not be accepted for bunkers. Coal above a certain standard, to be agreed upon for each district, should be penalised by a deduction of, say, 1 per cent. for each per cent. excess of moisture.

As a first tentative suggestion, I may perhaps indicate:—

	Per cent.
Welsh Durham	3
South Yorkshire	5
Northumberland	7·5
Derbyshire and Nottinghamshire	9
Lancashire, Warwickshire, and South Staffordshire	11
Scotch, hard	10
,, soft	13
West German	3
Eastern U.S.A. bunker coal	3
Best Pacific bunker coal	6

Slack, at least 1 per cent. above these values.

It is admitted that the figures already given for the influence of various factors are far from ideal, and it is certain that a considerable amount of work must be accomplished before a reasonably reliable standard of purchase to cover the wide range of bunker coal sold throughout the world can be introduced.

Before proceeding further, let me emphasise the importance

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of correct sampling. The objections and opposition to existing methods of paying for coal on quality are all chiefly rooted in unsuitable sampling. There is an ample supply of literature available on this subject, and a few publications are mention in the bibliography on page 293.

TABLE VI.

HEAT LOSSES. PERCENTAGE OF MOISTURE.

Gas leaving Temperature, Degrees C.	150	175	200	225	250	275	300
„ F.	302	347	392	437	482	527	572
Loss per kg. fuel, cal. per kg.	6·64	6·76	6·87	6·99	7·11	7·22	7·34
B.Th.U's. per lb.	11.95	12·17	12·37	12·58	12·80	13·00	13·21
Degrees C.	325	350	375	400	425	450	—
„ F.	617	662	707	752	797	842	—
Cal. per kg.	7·46	7·59	7·71	7·83	7·95	8·08	—
B.Th.U's. per lb.	13·43	13·66	13·88	14·09	14·31	14·54	—

It is not too much to expect that all coal merchants should in future buy all their cargoes on specifications and sample, and it should then be a relatively easy matter for them to give all the necessary particulars when quoting prices. Even then it may be prudent for the shipowner to sample his bunker coal. In this connection it is worth remarking that coal stored in heaps or bunkers is liable to classify itself somewhat automatically—the fines gathering together, for instance—so if special attention is not given to this point the various redeliveries may vary considerably in quality, apart from the accumulation of moisture. Imagine uncovered coal heaps in a rainy climate!

Opposition to buying coal on specification may be expected from the coal trade and the collieries, and only co-operation of the consumers on an extensive scale will overcome such

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opposition. It is certain to occur as soon as shipping circles become aware of the shortcomings of present methods, and of the great financial savings possible.

The best way of practically expressing the influence of coal quality on boiler efficiency is not an easy matter. In my opinion, possibly the best solution would be to adopt the term

Coal efficiency $\eta c =$

the ratio of the consumptions per hour of the coal in question to an assumed standard coal with a calorific heating value $Hcst$ and an assumed boiler efficiency ηbst.

This probably gives the best and most comprehensive picture of the real coal value, and being a ratio always yields correct relative values. Another method, perhaps nearer present practice, would be to deduct the losses* in the boiler from the calorific heating values of the coal. The rest, *i.e.*, the amount of coal transferred to steam, might perhaps be termed the

Boiler heating value Hb.

I must expressly point out that ηc and Hb are constants for a certain boiler under certain operating conditions only, and depend upon the design, equipment, and operation of the boiler plant, the most important single factors probably being the degree of forcing necessary, the draught available, the temperature of the combustion air, and the skill of stoking.

For ordinary marine conditions with natural draught, average values should be possible, however, which will sufficiently accurately indicate the relative values of the different qualities of bunker coal.

* Some of these losses, especially perhaps boiler radiation and loss owing to dirty heating surfaces, are not really due to the coal, or only partly so; but the first is fairly constant with all coals, and the differences in the second may be fairly ascribed to the coal, provided effective soot-blowers are properly installed and used; therefore I consider this to be of no practical importance.

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The mathematical expressions for Hb and ηc become then

$$Hb = \eta b \,.\, Hc.$$

$$\eta c = \frac{Hb}{Hbst} = \frac{\eta b \,.\, Hc}{Hbst} = \frac{\eta b \,.\, Hc}{\eta bst \,.\, Hcst}.$$

$$\eta c \text{ in per cent.} = 100\,\frac{Hb}{Hbst}.$$

Hb will be constant for both gross and nett calorific values, and $Hbst$ might be based on the assumption of the leaving temperature being equal to the temperature of the saturated steam produced, but as this would be impractical, a certain temperature might be arbitrarily fixed, say, 200 degrees C. or even 150 degrees C. In both cases the objection may be fairly raised that ηbst, $Hcst$, *and* $Hbst$ are mere imaginary values, which is the case.

The influence of coal quality on boiler efficiency expresses itself, as stated before, mainly on the amount of excess air necessary, losses in refuse, flying dust, soot, etc., but to make the value of various coal qualities clear in this respect, it is absolutely necessary to sum them up in one easily understandable figure. I think those suggested above are the best obtainable at present, and admit that when it comes to the practical determination of numerical values there will always be a risk that other factors, which have nothing to do with the coal quality, may disturb the results. This risk is considerably aggravated by the relatively large degree of inaccuracy common to boiler tests.

These objections are due to the nature of the matter considered, however, and are unavoidable with any term of expression. According to the results of the investigations published and previously discussed, the nearest approximation we at present can reach in the estimation of ηc and Hb will be to estimate the reduction of boiler efficiency owing to ash, a per cent.; volatile matter, v per cent.; and fines, f per cent.—see the discussion on pages 269

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to 278, and Figs. 2 to 7. The probable relative consumption of two coals with nett calorific heating values Hc_1 and Hc_2 will then become

$$\frac{\eta c_1}{\eta c_2} = \frac{Hc_1 \cdot \eta b_1}{Hc_2 \cdot \eta b_2} = \frac{Hc_1 \cdot (100 - a_1) \cdot (100 - v_1) \cdot (100 - f_1)}{Hc_2 \cdot (100 - a_2) \cdot (100 - v_2) \cdot (100 - f_2)}*$$

which means that

$$\eta b = \eta bst \cdot (100 - a) \cdot (100 - v) \cdot (100 - f).*$$

The important consideration of the behaviour of the coal on the fire is then assumed to be included when fixing the values of a.

To sum up, it may be stated regarding the influence of coal quality on boiler efficiency that:—

1. The real value of coal for boiler purposes is not indicated by either the calorific gross or the calorific nett value, but depends upon its behaviour in the furnace, which again, to a large extent, is indicated by the percentages of volatile matter, ash, and fines present, and the difference between the fusion point of the ash and the maximum temperature of the fuel-bed.

2. The degree of influence of these factors varies very much with the design of furnaces and combustion spaces, the strength of the draught available, and the method and skill of stoking.

While their influence with carefully operated mechanical stokers and suitably designed furnaces for the fuel fired may be practically *nil*, as far as volatile matter is concerned, and may be relatively unimportant otherwise, it is very far from being the case with the hand-fired Scotch boiler under average marine operating conditions.

3. The present state of our knowledge does not permit of estimating these influences with sufficient certainty. To enable us to do so, investigations ought to be commenced at once.

* If gross heating values are used a further correction factor for moisture will be necessary.

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4. Any method for scientifically purchasing bunker coal which does not consider the influence of the coal quality on boiler efficiency will not prove satisfactory in practice.

5. A good self-cleaning mechanical stoker suitable for marine conditions and Scotch boilers would be a great improvement, and save large amounts for the shipping trade.

It is now left to investigate

THE INFLUENCE OF THE WEIGHT OF, OR BULK TAKEN UP BY, THE BUNKER COAL,

on its real value to the shipowner.

This influence is due to the fact that a steamship has to carry the coal to be consumed during the trip, or round trip, to a certain bunker station, plus a suitable reserve, and this quantity must, of course, be deducted from the deadweight capacity to find the amount of cargo carried. Accordingly, for every ton of bunker coal carried the operator loses the nett value of one ton of freight, that is, the freight per ton minus all expenses charged, such as broker's commission, loading and unloading expenses, dunnage, and all harbour and similar expenses. Therefore, if the

Nett deadweight of the vessel, including bunkers is - - - -	DW tons
Quantity of bunkers carried - -	B ,,
Cost trimmed of the bunkers taken -	Cb per ton
Freight rate - - - - -	Fg ,, ,,
Total expenses charged per ton freight	Exf ,, ,,
Nett freight value - - - -	Fn ,, ,,

then, of course, the freight revenue minus the expense due to the quantity of freight carried (the other expenses can be taken as constant as far as the bunker quantity is concerned) minus the cost of the bunkers, or

$$(DW - B) \cdot (Fg - Exf) - B \cdot Cb = (DW - B)Fn - BCb = DWFn - B(Cb + Fn).$$

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Or, the influence of this factor is simply represented by *adding the nett freight value per ton* to the cost of the bunker coal trimmed per ton.

In this formula neither the coal quality nor the spare coal left unconsumed, and its different value at the point of destination, is considered. The influence of the first is determined as follows:—The coal efficiency ηc, or the boiler heating value Hb, being given, as well as the consumption per 24 hours, c_{24} of the assumed standard coal, the probable length of voyage L, the quantity of spare coal deemed necessary R, and the port consumption before next bunkering P, both expressed in days of 24 hours full steaming, then

$$B = (L + R + P) \cdot c_{24} \cdot \frac{Hbst}{Hb}.$$

The difference in income when using two kinds of bunker coal, B_1 and B_2, thus becomes

$$B_1.(Cb_1 + Fn) - B_2.(Cb_2 + Fn) =$$

$$H + bst.(L + R + P) \cdot c_{24} \cdot \left\{ \frac{Cb_1 + Fn}{Hb_1} - \frac{Cb_2 + Fn}{Hb_2} \right\} =$$

$$(L + R + P) \cdot c_{24} \cdot \left\{ \frac{Cb_1 + Fn}{\eta c_1} - \frac{Cb_2 + Fn}{\eta c_2} \right\},$$

or the cost per 10,000 units of boiler heating value of the coal trimmed in bunkers plus the nett freight value (plus, strictly speaking, the cost of transporting and firing the coal and removing and disposing of the refuse). For marine purposes the crew carried will be constant, and the other expenses also practically remain constant; with large differences in quality it is quite imaginable that the number of the crew has to be changed, and then it becomes a matter of importance when comparing the values of the fuels under consideration.

Thus

$$\frac{Cb + Fn}{Hb_1}, \text{ or}$$

$$\frac{Cb + Fn}{\eta c}$$

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is the factor expressing *the value of the bunker coal* disregarding the eventual difference in value of the coal in the spare bunkers.

The latter is usually unimportant, and will in the long run, under ordinary circumstances, practically balance, and may, therefore, be left out of consideration. For a single trip, or near the end of a time charter, or with sudden market fluctuations, including strikes, this influence may be of importance to the absolute result, although it will not even then direct the choice of bunker quality.

In some cases double-bottom tanks have been used to carry oil for the use of other vessels of the same company, or for sale, but such extra quantities cannot fairly be considered as bunkers, as they are really part of the cargo, and must be treated and accounted for accordingly. Round trips are best considered each way separately; if bunkers are carried for the whole trip, F*n* for the return trip is, of course, the sum of the value for both the outward and the return voyage.

There are, however, certain difficulties in using these formulæ. There is great uncertainty at present in estimating the effective boiler heating value H*nb*, which, as has been shown, may vary very considerably from the nett calorific value of the coal as delivered.

The formula suggested on page 283 is just a first rough suggestion for starting a discussion.

The determination of the expenses due to the quantity of extra freight E*xf*, and thus the nett freight value F*n*, needs also special care.

Often part of the bunker coal carried may on round trips be worth two (or even more) cargoes, one on the outward and one on the homeward trip, and both must, of course, be added for that part of the bunker coal. In fact, it may even pay to use a better grade of bunker coal for part of the trip. If the ordinary bunkers and spare bunkers do not suffice, it may be necessary to partition off part of a hold, and the expenses

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connected therewith and for transforming this quantity to the ordinary bunkers must, reduced per ton, be added to the bunkers' cost per ton Cb. When finishing there will be a certain amount left. This must, of course, be credited to the next trip at the correct value of the start of such trip, and the difference must also be allowed for, to obtain correct results.

On the other hand, there may be cases where the increased quantity of cargo possible, owing to better bunkers, is not available, and the owner, according to the charter party, is not entitled to payment for more than the cargo carried, or the freight may be a lump sum, and then Fn is, of course, 0 for such cases, as it is also for ballast trips. The increased cargo may cause increased stowage or increased time for loading and discharging, and the expenses due to such items must be charged and deducted when determining Fn.

In most cases with capacity cargoes it is not the weight but the space taken that is the deciding factor for the quantity of cargo carriable, and then the necessary space per ton of coal—perhaps I may call it the apparent specific gravity—also enters, but otherwise the method is the same. The permanent bunkers cannot ordinarily be used for cargo, and for shorter trips it will, therefore, often be impossible to utilise any advantage of better coal, again making $Fn = 0$.

In case of intermediate bunkering, time loss, extra distance steamed, harbour and pilotage expenses, etc., must be added to the coal price; this is only mentioned for the sake of completeness. An example with assumed figures may perhaps be of interest. A 10,000-ton deadweight tramp vessel is assumed to be lying in Swansea chartered with coal $Fn = 10/-$ to Buenos Aires, and from there with grain $Fn = 25/-$ to Marseilles. Three quotations for bunkers in Swansea and two more in Buenos Aires are assumed (see Table VII) to be under consideration, with the necessary data for quality. From the calculated values for $\frac{Cb + Fn}{Hb}$ it will be seen that coal No. 2,

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Table VII.

Assumptions: $Hcst = 8{,}000$ Cal. $= 14{,}400$ B.Th.U's. $\eta bst = 80$ Per Cent. $Hbst = 6{,}400$ Cal. $= 11{,}520$ B.Th.U's.

Quality.	Price per Ton f.o.b. Trimmed.	Calorimetric Nett Heating Value.		Cost per 10,000 Units Nett Calorimetric Heating Value.		Approximate Analyses as Delivered. Per cent.			Efficiency Reduction Per cent.		
		Cal.	B.Th.U's.	Cal.	B.Th.U's.	Ash.	Volatiles.	Fines.	Ash.	Volatiles.	Fines.
1. Best Admiralty hand-picked smokeless	35/- Swansea -	8,000	14,400	43/9	24/3·7	5·2	15·4	15	2·7	0	3
2. Best hand-picked Welsh steam - -	31/6 „ -	7,730	13,915	40/9	22/7·7	5·6	29·0	10	3·1	4·5	1·5
3. Screened steam - - - - -	25/- „ -	6,650	11,970	37/7·1	20/10·6	16·2	35·0	10	15·5	6·7	1·5
4. Best Welsh smokeless - - -	48/- Buenos Aires*	8,000	14,400	60/-	33/4	5·2	15·4	25	2·7	0	6·0
5. Best Welsh smokeless, extra screened at Buenos Aires when delivered -	48/6 „ „	8,000	14,400	60/9	33/8·2	5·0	15·4	10	2·5	0	1·5

	Coal Efficiency, ηc. per cent.	Boiler Heating Value, Hb.		Cost per 10,000 Units Boiler Heating Value.		$\frac{(Cb+Fn).10^4}{(Hb)}$		Differences I as Base.	
		Cal.	B.Th.U's.	Cal.	B.Th.U's.	Outward.	Return.	Outward.	Return.
1	94·4	6,020	10,835	58/2	32/4	74·75	116·28	—	—
2	91·1	5,630	10,135	55/11½	31/1	73·71	118·12	−1·04	+1·84
3	77·7	4,135	7,440	60/6	33/7¼	84·64	145·10	+9·89	+28·82
4	91·4	5,850	10,530	82/0½	45/7	—	124·79	—	+8·51
5	96·0	6,140	11,050	79/0	43/10½	—	119·71	—	+2·43

* Such a price would only be possible if the screenings were utilised by coal-dust firing.

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Coal No.	III.			
	Weights.	Rates.	Expenses.	Income.
Outward.				
Deadweigh	10,000			
Bunkers ca	1,530†	25/0	£1,912 10 0	
Freight cha				
turn bun	1 360§	10/0		£680 0 0
Cargo carri	7,110	10/0		3,555 0 0
Balance ou			2.322 10 0	
			£4,235 0 0	£4,235 0 0
Homeward.				
Deadweight	10,000			
Bunkers ca	1,360	35/0	£2,380 0 0	
Cargo carri	8,640	25/0		£10,800 0 0
Balance, exc			8,420 0 0	
			£10,800 0 0	£10,800 0 0
Balance, excl				£8,420 0 0
Spares left	170	24/8¼		209 16 11
Balance, incl			£8.539 16 11	
			£8,539 16 11	£8,539 16 11

eward.
included.

) 16 1½
5 1 10
5 5 8½

* Exact

§ Exact figure calculated, 1,361·2.

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under the conditions given, will be the most favourable for the outward voyage and the port consumption in Buenos Aires, whereas No. 1 coal is the best for the homeward voyage and spare bunkers for that voyage. The difference between No. 2 and No. 1 is too small, however, to make its use outward advisable. It will, therefore, not pay to bunker in Buenos Aires, and, if correctly calculated, it will probably not often be found to pay to bunker imported coal at overseas end ports, if starting from a coal export harbour, where *high-grade* bunkers are available. It will further be seen, from the cost per 10,000 heat units of boiler heating value, that even if the vessel was starting in ballast $Fn=0$, it would not pay to burn coal No. 3. This may appear strange since the vessel is starting from a large coal export harbour, but the explanation is that the efficiency of this coal ηc when burnt by a mechanical stoker of a modern stationary boiler plant will be very much higher, say perhaps 95 per cent. instead of 77·7 per cent., which would mean $Hb=6{,}320$, a cost of boiler heating value of 39s. $6\frac{3}{4}$d. per 10,000 cal., or 21s. $11\frac{3}{4}$d. per 10,000 B.Th.U's. If we take Fn, which for a stationary plant would mean the cost of the freight and handling the coal per ton until delivered in the boiler-room overhead bunker, or on the firing floor, plus the cost of handling the refuse per ton of coal, $=5{\cdot}0$, $\frac{Cb+Fn}{Hb}\,b$ becomes $=47{\cdot}47$, and thus changes the conditions completely. Another reason, of perhaps still greater importance at present, is the general under-estimation of the economic importance of coal quality and the lure of the apparent cheapness of 25s. as compared with 31s. 6d., not to mention 35s.

To show how far the results may be influenced by the variation in value of the spare bunkers, the complete accounts for the first three qualities have been worked out in Table VIII, it being assumed that the most favourable coal quotation is Marseilles. As an extreme case, the vessel is assumed to have

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obtained a very good charter, and that the coal has increased in price, giving in Marseilles $Cb = 45s.$, $Fn = 27s.$, and $Hb = 5{,}760$ cal.

$$10^4 \cdot \frac{Cb + Fn}{Hb} = 125.$$

The consumption per 24 hours of an assumed standard coal with a boiler heating value = 6,400 cal. = 11,520 B.Th.U's. is assumed to be 36 tons, with an average speed of about 10 knots; the time from Swansea to Buenos Aires is estimated at 26 days, and from Buenos Aires to Marseilles at 21·5 days. For port consumption at Buenos Aires 54 tons of the assumed standard coal is added, and spare for three days' steaming. It will be seen that the influence of variation of the value of the spare bunkers is relatively unimportant. The value of the spare bunkers at Marseilles is calculated as follows:—

$$10^4 \cdot \frac{(Cbs + Fn)}{Hbs} = 10^4 \frac{(Cb + Fn)}{Hb} \quad Cbs = \frac{Hbs}{Hb}(Cb + Fn) - Fn.$$

Cbs = the value of the spare bunker supply at port of bunkering.

Cb = the cost of the most economical bunker at port of bunkering.

From these investigations, the following conclusions confirming more or less well-known facts may be drawn:—

1. *The higher the nett freight value, the better should be the grade of bunkers chosen.* This is also one of the main reasons why fast liners can use oil fuel to greater advantage than other vessels, and taken in the widest sense this still more applies to warships, although they carry no cargo at all and liners next to nothing, but the value of each ton less of bunkers is, nevertheless, very high in both cases.

2. The proper use of steam coal is to burn the most inferior grades at the pit mouth, the next inferior grades in its environs, and *as the cost of transport—the nett freight value comes under this classification—increases, the quality used*

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should also improve. For various reasons these ideals are still somewhat distant.

To be burnt efficiently low-grade coals usually require special arrangements, such as coal-dust firing, mechanical stokers with artificial draught, special furnaces with ignition arches, special grates, for instance plate grates with fine holes and forced draught, etc., and such appliances are often not available and not practicable in locomotives and steamships. Collieries are often accused of burning their fuel with little regard to economy, and in many cases such charges seem to be not altogether unfounded. They ought to use the most inferior grades.

As long as inferior grades were very cheap and coal altogether relatively cheap, it is at least understandable that not too much regard was paid to fuel economy, as expensive arrangements for that object would not pay, but it is quite curious to find in Sweden, for instance, special grates for burning Welsh slack.

3. An easily worked boiler commanding ample draught can usually burn with advantage a lower grade of coal than others not possessing such advantages, and the choice for a boiler on the small side with poor draught is very limited indeed if a reasonably good efficiency is to be secured.

4. Good stoking and proper control are of great importance, to obtain which, means suitable instruments for combustion control; the latter are remarkably absent on board ship. For this reason, together with the lack of knowledge, skill, and interest on the part of the crew in the performance of their vessel, and misunderstanding of the savings possible on behalf of the shipowner, I am perfectly satisfied that with a more suitable supervision, and better purchase and operation, at least 15 per cent. of the total quantity of bunkers consumed at present can be saved.

5. Mechanical stokers permit of the use of very much lower grades of coal with the same furnace efficiency than hand-

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fired ones; in fact, this is one of the greatest advantages of such arrangements.

They enable higher efficiencies to be regularly maintained, and, much better, maintain a regular steam pressure (not always the case with hand-cleaned stokers).

They greatly reduce the amount of human labour necessary. In large stationary plants with self-cleaning multiple retorts, underfed or travelling-grate stokers with mechanical coal and ash transport, approximately from 75 to 80 per cent. of the labour is saved.

They elevate labour from hot, hard, physical toil to the intelligent running of the stoker (hand-cleaned stokers again excepted), thus enabling a better grade of operators to be obtained and kept.

Owing to all these advantages, the question of suitable mechanical stokers for marine purposes should be energetically followed up, as the advantages will be great, even if it means the adoption of water-tube boilers. With good mechanical stokers and sufficiently large combustion spaces properly operated, the influence of volatile matter on boiler efficiency will, as before mentioned, probably be next to nothing, and that of the ash reduced to from 0·3 to 1 per cent., according to furnace design, type of ash, etc. The savings possible are, therefore, apt to be very substantial.

6. Under present average marine conditions bunker coal quality is of much greater importance than is usually suspected, and it will pay well to take precautions to secure the most suitable high-grade coal, which should be properly sampled and analysed.

I feel that this question of the correct purchase of bunker coal has not received anything like the attention it deserves, and if this paper should be instrumental in awakening greater interest in this important subject, my object will have been achieved.

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BIBLIOGRAPHY.

J. S. S. Brame. Fuel, Solid, Liquid and Gaseous. London, 1914, p. 350.

G. Dilner. Om Stenkol och Stenkolsinköp. Stockholm, 1914, pp. 51-57.

F. W. Hinrichsen & S. Taczak. Die Chemie der Kohle. 1916.

W. Hans. Rationeller Kohleneinkauf. Freiberg, i. Sa. 1913.

E. H. Tenney. Test Methods for Steam Power Plants. New York, 1915, pp. 2-10.

C. R. Hodgson. How Coal Should be Sold. Power, 1922, p. 659.

The Iron and Coal Trades Review. Leader, Selling Coal under Guarantee. 28th March, 1913, p. 499.

Ibid. Standard Coal Specifications drawn up by a Committee of Coal Contractors and the Associated Municipal Electrical Engineers of Greater London. 28th March, 1913, p. 490.

E. C. Bailey. Accuracy of Sampling Coal. Journal of Industrial and Engineering Chemistry, 1909, pp. 162-176; is probably the fundamental article on the theory of this subject, and is a most important and interesting one.

O. Binder. Chemiker Zeitung. 1912, p. 893. Zeitschrift für Dampfkessel und Maschinenbetrieb. 1913, p. 524.

Dosch. Braunkohle. 1913, p. 531.

Furth. Wasser und Gas. 1913, p. 139.

G. M. Gill. Engineering. 1922, p. 52.

American Society for Testing Materials. Standards.

U.S.A. Bureau of Mines, Pittsburgh—

Technical Paper No. 76. A. C. Fieldner, Notes on Sampling and Analysis of Coal. Washington, 1914.

Technical Paper No. 133. G. S. Pope, Directions for Sampling Coal for Shipment or Delivery. Washington, 1917.

Bulletin 11. The Purchase of Coal by the Government under Specifications. G. S. Pope, 1911.

Bulletin 41. Government Coal Purchases under Specification. G. S. Pope, 1912.

Bulletin 63. Sampling Coal Deliveries. G. S. Pope, 1913, pp. 8-11, and 52-63.

Bulletin 116. Methods of Sampling Delivered Coal. G. S. Pope, 1918.

Zschimmer: Z.d. Bayerischen Revisions Vereins. 1913. No. 5 and ff.

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Discussion.

Mr. DONALD MACNICOLL (Member): Mr. Kahrs is attacking a very big problem, and, although I agree with his opening remarks, I cannot quite agree with his proposed solution for obtaining greater efficiency. Apart from the difference in calorific value between oil and coal fuel, the outstanding saving accruing from the use of oil is, broadly speaking, due to the fact that it does not require to be man-handled.

I am afraid that it would be a very difficult matter for shipowners and marine engineers to enforce a regulation that coal should be sold to them on their own terms, even if they were banded together for this purpose. On the other hand, I would suggest that there is immense scope for the preparation of coal so that it may be as easily handled on board ship as oil, and the solution appears to be pulverisation.

Mr. J. W. LIVINGSTONE JONES (Member): Mechanical stokers have engaged the attention of many engineers and boilermakers for years past, but, curiously enough, a mechanical stoker exactly suitable for the multi-tubular type of marine boiler has never been produced. At least 16 years ago it was thought that a particular stoker designed for marine purposes would be really effective. It started off exceedingly well, but for some reason or another after each voyage it seemed to become more unpopular, although it made good so far as steam production was concerned, and saved a considerable sum of money. The real reason for its unpopularity was that the engineers and the men in the stokehold did not like mechanical stokers on board, for it meant work for them while in port. It is, however, known that a reliable mechanical stoker has been evolved to work in conjunction with water-tube boilers, and that in this connection its application has already met with success.

With respect to the economical uses of coal, further steps are being taken, and, as Mr. MacNicoll remarks, more attention

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is being given to the pulverisation of coal, and particularly to the extraction of oils from coal before it actually leaves the colliery. It is known that if, say, one-third of the coal extracted from the pits in this country went through a process of low-temperature carbonisation, only about one-half of the oil presently shipped from abroad would need to be purchased by this country. Consideration of that fact alone will show what an enormous saving this would mean. It may be doubted whether such a thing is practicable or possible, but it may be said fairly optimistically that it will not be long before success is achieved on these lines. Many experts in this country, particularly since the Coal Commission was appointed, are engaged on the vital question of what can be done to improve the present position in our coal fields, and the Commission has considered this feature perhaps more than any other.

I am personally interested in a certain low-temperature carbonisation process, and recently visited Germany to see a plant working at Essen. There, dust coal from the mine was passed through a low-temperature carbonisation process, and the by-product, in the form of semi-coke, was sold at high prices round the district; the tar and benzol were also readily sold. For that particular coal there was a saving in money, but the conditions there are not exactly similar to those in Scotland, as here there is no similar waste coal in the pit. The problem here is to evolve a process to deal with the peculiar kind of duff coal which is at present abandoned.

Summing up the whole matter, it might be said that the two methods which will surely, but perhaps slowly, be adopted are the low-temperature carbonisation process at collieries for dealing with low-grade fuels, and pulverisation; the resultant semi-coke dust could be transported and used in a powdered-fuel installation with water-tube boilers on ships or on land. In view of the immense saving which would accrue, the sooner these methods arrive the better for the country's welfare.

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Mr. W. S. Watson.

Mr. W. S. Watson (Member of Council): Illustrations of chain grates and other kinds of mechanical stokers to be seen in technical journals are mostly shown under water-tube boilers, but I remember seeing, nearly 30 years ago, a Liverpool-made mechanical stoker applied to an ordinary Scotch boiler. At that time, with such an appliance, many thought that the majority of the firemen might be left ashore, but that was found impossible, as the ashes had to be got rid of and the fires had to be cleaned, so that the idea of saving in personnel was not realised. Mechanical troubles developed with the appliances for rocking the bars, and other difficulties were encountered to such a degree that engineers could not be persuaded to stay on the ship. The toil of the men was perpetual; even in port, when the men were entitled to have leave to return to their homes, they were compelled to work on, with a view to lessening the discomforts of the next voyage.

Mr. Kahrs seems to me to go a long way round to get to his goal compared with what has been done by a shrewd Glasgow shipowner. One of the speakers on a previous paper referred to the merits of the displacement feed-water meter, and I agree with all he said. These meters, made in this country, are quite good enough for indicating, broadly, the water consumption for steaming purposes. The shipowner I refer to ran boats from Cardiff to the northern ports of France. He did not mind whether his triple-expansion engine used 13½ lbs. of water or 15⅓ per i.h.p. per hour; primarily, he wanted to know how much it cost to boil 1,000 gallons of water. He put in a feed-water meter between the feed pump and the feed check valve, and by taking careful measurement and tallying his coal he found he was able to make a great saving in the cost of running the ship. He found also that it paid him better to purchase bunkers at 18s. per ton than to buy an inferior coal at 15s. per ton, as there was less ash to handle with the dearer coal and, consequently, the firemen were more contented.

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This shipowner discovered that as soon as he began to measure things he made economies, so that the introduction of measuring instruments, and, through them, the selection of a good quality of coal, will go a long way to reduce running costs.

Mr. T. H. Hill (Member): In the introduction to his paper, Mr. Kahrs definitely states that the practice of buying bunkers on a heat value basis has not yet been adopted. I think that consumers, in the main, possess much of the knowledge and are fully aware of the advantages to which he refers, but precedent is the chief stumbling block to progress on these lines. If sales on such a basis are granted to land installations, how can the collieries in reason defend their action in refusing the same sales basis for bunkers?

When Mr. Kahrs says that the "calorific value is not a sufficiently correct measure of the value of coal . . . as the quality of the coal affects the boiler efficiency very considerably," he raises a wall of distinction between heat value and quality that I find difficult to understand. Surely calorific value is the major factor in results which signify quality of coal. What exactly Mr. Kahrs' definition of the term "quality" is, I have not been able to grasp fully; it seems to vary somewhat throughout his paper.

Nothing short of an Act of Parliament would be necessary to obtain all the information required to establish Mr. Kahrs' "boiler heating value" and "coal efficiency" terms; and when he says that "even in the best cases . . . trade names do not give any knowledge as to the real value of the commodity paid for," he makes a sweeping assertion which is not in accord with the experience of the majority in this country. While there may be variations in value, they do not generally amount to much, and are hardly possible if purchasers will exercise a moderate measure of interest in their bunkers; but variations may, and possibly do, happen if purchasers will buy a "pig in a poke."

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Mr. T. H. Hill.

While there is reason to regret the amount of apathy on the question of scientific methods of buying bunkers, it is not the case that such methods have not been applied. I know of shipowners who, for the past 30 years at least, have made a regular practice of testing the calorific value of the bunkers offered them, and have recorded such tests, the steaming results, ash percentage, etc., and on various occasions when bunkers were not up to sample they obtained a rebate on the price paid. With these shipowners the procedure was, when a likely coal was offered, to request a sample, and if the calorific value, etc., obtained was favourable, one lot of bunkers was ordered. A further average sample was then taken from this lot and tested for calorific value. The steaming results, ash percentage, etc., were obtained, and further orders depended upon the results. It must be admitted that such regular and desirable procedure in the purchase of bunkers is not as common as it should be. If it were, it would sufficiently and accurately indicate the relative values of the different qualities of bunker coal. Mr. Kahrs gives reasons why scientific methods of coal buying have not yet been practised, and says that these reasons do not apply to the U.S. Naval authorities, although they do not buy bunkers on a scientific basis. Perhaps he will say why he gives them such preferential treatment.

Research on the lines indicated by Mr. Kahrs is desirable, and indeed long overdue. Much has been heard about the conservation of coal and coal supplies, but through lack of research on definite and comprehensive lines the owners of inefficient plant, including boilers and engines, are not convinced nor made sufficiently aware of how much they are contributing to the unnecessary waste of this valuable mineral. Had consumers of bunkers in the past been prepared to set aside for research, say, a very small percentage of their annual coal bill, users might have been able to-day to record greater efficiencies. If Mr. Kahrs could arrange a 15 per cent. saving

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formula in such a manner, and include as one of the factors this annual contribution from coal consumers, the successful application of that formula would result in posterity rising up and calling him blessed.

The following is a brief extract from a masterly preface to "A Rudimentary Treatise on Fuel," published in 1853 by a gentleman who anticipated much of to-day's progress in combustion engineering:—

"Has then anything like the amount of intellect been devoted to the examination of this subject of economy of fuel which the magnitude of the interests involved in it, and its importance in a national point of view, render it deserving of? Are the processes and appliances we have recourse to, the result of careful deductions, made from a searching and scientific consideration of the question from an elevated point of view, untrammelled by those narrow notions which daily routine too frequently engenders; or rather, have not methods and systems, which originated at a period of comparative darkness in physical science, been continued from habit down to the present day, without adequate reflection and research?"

Mr. Kahrs refers to the percentage of fines affecting the value of coal, but I would submit that the quality of the fines or slack is a more important factor, which will be borne out by all who have had experience with the burning of large quantities of slack at sea. I agree with him that "a mechanical stoker suitable for marine conditions would save large amounts," but unfortunately those interested have waited long, and are still waiting, for that suitable mechanical stoker. I agree also that good stoking and proper control are of great importance, and that maximum efficiency will not be obtained until suitable measuring instruments are provided. If such instruments formed part of the vessel's equipment, I have no doubt concerning the required knowledge, skill, and interest on the part of the crew in the vessel's performance.

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Mr. T. H. Hill.

What usually takes place on board ship? On the steam side of the generator, engineers are much concerned about the pressure and dryness of the steam, and through the various expansion stages they measure its performance, and particularly record the temperature and pressure of its dying breath. Finally, they ensure that, in its transformed state, it will take the straight and narrow path back to the boiler. Now on the combustion side of the same generator, with the few exceptions mentioned, what takes place? Briefly, a certain amount of fuel is thrown into the furnace, and in the case of natural draught the pressure gauge is about the only instrument consulted; with forced draught there is in addition a draught gauge. Outside of this, the remainder is largely guesswork or rule of thumb procedure.

I am confident that with efficient control on the combustion side of the generator a saving of at least 10 per cent. could be effected, and the maximum efficiency can only be obtained where carbon-dioxide recorders, draught gauges, and pyrometers are fitted. It should be possible to take regular temperature readings from each combustion chamber, smoke-box, and uptake or funnel base. The lack of combustion-chamber temperatures has always appealed to me as a decidedly weak point in boiler control, and if these were obtained the wasters among the stokers would soon be spotted, and the output of each furnace controlled in a scientific and regular manner. In addition, I am of opinion that all foreign-going steamers should be provided with a fuel calorimeter.

I agree with Mr. Kahrs' final sentence.

Mr. A. Campbell (Member): Bunker coal is the source of most of the troubles the sea-going engineer has to contend with, and especially so with the various brands supplied at foreign coaling stations, which are handled so often between the pit and their destination that they contain a large percentage of fines. Moreover, they may lie for months exposed

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Mr. A. Campbell.

to all sorts of weather, so that when shipped as bunkers the calorific value is considerably reduced from that at the pithead.

A simple device for testing the calorific value of the coal put on board is an excellent idea, but the taking of tests and payment by results would require to be mutually agreed upon between the shipowner and the coal contractor. I cannot imagine such an agreement being put into common practice this side of the millennium. As a rule the tramp owner is not interested in the quality of bunkers supplied at the various coaling stations, as long as the result of the voyages leaves a profit in his favour.

Generally speaking, the boiler power on steamers is too small, and the ventilation very inferior. I have known the temperature of a stokehold in the tropics to be 150 degrees F. Under such conditions it is no use thinking of the ideal method of firing—little and often. It is simply a question of filling up the furnaces and getting on deck for fresh air. Consequently the efficiency of the boilers may be somewhere in the region of 50 per cent., whereas for mechanical stokers or pulverised coal an efficiency of from 80 to 90 per cent. is claimed.

Both mechanical stoking and pulverised coal plants are excellent devices for land boilers, but too cumbersome and costly for sea service. Even if they were installed for the proper handling of such plants, additional engineers would have to be carried, so I think most owners prefer the old style.

The most reasonable method of saving coal on steamers is to have ample boiler power to allow the coal time to burn, or, as understood by engineers, to have an easy steaming job. Good ventilation is also essential, thereby providing more comfortable conditions for the stokers, and enabling them to take more interest in their work in the stokehold. Under these conditions, I feel certain that Mr. Kahrs' suggested saving of 15 per cent. of the coal bill will become an established fact.

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Mr. L. Marshall Jockel.

Mr. L. MARSHALL JOCKEL (Member): Some of Mr. Kahrs' suggestions are extremely ingenious, but I am rather afraid that the basis of purchasing bunker coal will remain much on its present lines for a good many years to come. The volatile content of the coal and its ash characteristics are well known to be of great importance in purchasing. The present system in vogue among colliery owners and agents will have to be completely transformed before scientific purchasing becomes possible.

Mr. R. RATTCLIFF STEEL: I should like to say that this subject has for a long time appealed to me and interested me very much, and although at first sight it seems easy to deal with, the more it is studied the more difficult it becomes. I appreciate the way in which Mr. Kahrs handles the matter, since he seems to recognise the other side and does not, like many people who have a pet theory, try to overlook the practical difficulties. I am afraid I have not at the moment time to make a thorough criticism, but in reading the paper through the following are the practical difficulties which I foresee:—

Firstly, in laboratory tests all low volatile coals, although generally more efficient for bunker purposes, show relatively lower in calories compared with high volatile coals. For example, the best Welsh, best Yorkshire, best Durham, and best Scotch coals with equal percentages of ash will, I believe, all show round about 8,000 calories, but nobody, I think, would suggest that any of these other qualities can compare at equal prices with Welsh coal for raising steam in marine boilers, even although the calorific value may show much about the same.

Secondly, the depots would require to ask higher prices to cover the risk they would thus have to take, and, generally speaking, the shipowner would not pay the higher price. At present he prefers to get his coal as cheaply as possible and take the risk himself, as he always hopes he will be lucky.

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Suppose that bunkers were sold on this basis to shipowners who desired to purchase in that way. It will certainly be appreciated that it would be necessary to ask a somewhat higher price from them than from purchasers who are willing to take the risk of how the test might turn out.

Thirdly, there is the difficulty of obtaining a really average sample. This difficulty is still greater if the question of percentage of small has to be considered.

Fourthly, any such system lends itself to bribery. Only a little while ago I heard of a case where a bunker supplier on the Continent was selling to a steamship company on analysis. Each lighter had in a certain place a corner of good coal, and for some time the supplier managed to arrange for the samples to be taken from these particular corners. Even if no such elaborate process is arranged, a great deal must depend upon the engineer and the supplier as to what kind of a sample is obtained.

If a commencement has to be made in this matter, I think it would be sufficient to start with a guarantee that the coals are not a mixture varying more than within a certain minimum and maximum percentage of volatiles, and a maximum percentage of ash. With such figures laid down shipowners would, I think, be sufficiently safeguarded, and it would materially facilitate matters. If a start is made with too elaborate and difficult suggestions, it will be very difficult to make any change.

Mr. J. S. Thomson: So far as my personal views are concerned, I appreciate very much the exhaustive study shown in this paper, but there are a great many elements which, I think, make it almost impossible to bring the coals used in ships' bunkers on to the same plane as that used in land boilers. One of the first considerations is the actual nature of the coals when on the fires, and three main features arise out of that: primarily, whether they have coking or caking

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Mr. J. S. Thomson.
tendencies or burn quite freely; secondly, whether the coals open out under combustion in cauliflower manner; and thirdly, the behaviour of the ash.

In analysis, particularly in laboratories, good results can be obtained by mixing different grades of coal, yet in actual practice these mixed coals are never consistent unless of similar nature and behaviour on the fire. It is practically impossible to get coals of a different nature to avoid drawing apart, yet I have often seen mixtures of heavily-burning coal and a light free-burning coal giving results in a laboratory which should give excellent results in steaming.

The greatest objection to selling coal under guarantees other than ash contents, to my mind, is the impossibility of finding reliable sampling of coal, and in any case this would lead to more scope for graft than the existing basis of coal buying.

Mr. Kahrs emphasises the desirability of some arrangement of mechanical stoking. This is theoretically ideal, but I take leave to doubt any economic effect from it. Look at recent developments with mechanical stokers on land, where they are essentially the right element. Mechanical stoking was originated primarily for the use of dross in small-sized coal. As I understand it, collieries had difficulty in selling this coal as it came from the mine. This led to the introduction of washing, and following the washing came the introduction of the mechanical stokers. My sequence of these events may be wrong, but the fact cannot be ignored that the small-sized washed coals have of recent years been far too dear. They contain a heavy percentage of moisture, and, generally speaking, have a lower calorific value than large coal, while the ash contents of the large and washed nuts show little difference. But the price of washed coal, instead of being less than large coal, has been for years shillings per ton more, and this is attributable directly to the tremendous increase of mechanical stokers and the users restricting themselves entirely to one

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quality or size. It has resolved itself into an excessive price being paid for a specified article irrespective of the competing value.

Steamers on a trade route also may have four or five different native coals on board. They may take Japanese coal, then Indian coal, then Natal coal, followed with Welsh or Durham, all on one voyage. The nature of each of these coals is vastly different, and an expert engineer with good trimmers will treat them in a different way when firing. The human element fails far more than the coal does, and I do not see how the human element can be eliminated from ships' bunkering.

Another point is that efficient shipowners, far from being conservative, as suggested by Mr. Kahrs, are, in my opinion, always ready to, and actually do, investigate coal and its effect in their boilers very closely, but from experience there is the strange fact that sometimes inferior coals have given actually a more economical result than slightly better coals. When I use the term "inferior," I do not mean poor coal, but something a little lower than the absolute best. Boilers on steamships, unlike land boilers, have many peculiarities. Two steamships are built at the same time, exact duplicates, yet both in speed and coal consumption there is a marked difference between the two. The owner then has to study the coal for each boat, which he does first of all from the theoretical or laboratory side, and then from the results obtained, and it is the practical tests that he actually goes by in the long run.

The greatest weakness of all, however, is the human element in firing, and there seems to be no method of overcoming this. No matter how carefully and scientifically the coal may be selected, the trimmers can entirely wreck the result. Mostly they do so by renewing their fires too late, and with a corresponding loss of steam. They then fire too heavily, causing further loss of steam, and then start slicing, in many cases when the slice is not necessary, but in all cases when the fire

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Mr. J. S. Thomson.
is not ready, and the result means forcing of unconsumed coal through the fire-bars.

Lastly, the fusing of the ash is one of the worst things to overcome, and I do not quite see how, on a long voyage, confusion under guarantees dealing with fusibility can be obviated. Economically, it is essential to take native coals at certain places, and it is probable that at the second stage of a voyage the ship is getting a coal with fusible ash. At the third stage she may get a coal with non-fusible ash, but the two coals will inevitably be mixed in the bunkers, and the non-fusible ash will then become fusible. Although a laboratory test will prove the non-fusible ash as such, the shipowner will at once doubt the sampling of the coal when he knows that clinker has formed.

Col. J. R. S. Leslie: Mr. Kahrs handles his subject in a most thorough and painstaking manner, but I am rather afraid that very few shipowners, at least so far as my experience goes, would be prepared to tackle the question of bunker coal in such a highly scientific manner.

I entirely agree with the remarks made by Mr. Steel and Mr. Thomson regarding the sampling and analysis of coal supplied for bunker purposes. In addition thereto, the cost of proper sampling and analysis would, to my mind, be a serious item if performed in a thorough manner. From practical experience, the number of wagons of coal from which a sampler could draw really representative samples in a day is limited. Further, really representative samples could not be obtained from the top of any wagon, and consequently the side doors of the wagon would require to be opened, which would entail great expense. If sampling of any parcel of bunker coal were to be carried out, the only practical method would be to do it at the pithead as the coal is passing over the picking table. Generally speaking, the cost of thorough sampling and analysis of consignments of bunker coal would

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on the average be not less than about 3d. per ton, and I question if it would be possible to get both coalmasters and shipowners to agree to such a charge, and to accept the analysis obtained.

From experience with mechanical stokers in connection with land boilers, I am afraid their adaptability for marine purposes would be a very difficult subject to tackle. From the point of view of a supplier of bunker coal in Scotland, I should say that mechanical stokers, so far as Scotch coal is concerned, are not desirable. As Mr. Kahrs is probably aware, and as Mr. Thomson points out in his remarks, the benefits derived from mechanical stokers in connection with land boilers originate in the fact that the fuel used with mechanical stokers is of the variety known as washed nuts, and when this class of material is departed from, the benefits are practically *nil*. A large proportion of Scotch bunker coal, of the better class particularly, is of a coking or caking nature while in the boiler fires, and this class of material would be entirely unsuitable for use with mechanical stokers. I have personally had the experience of supplying washed nuts from a fatty coal of a strongly caking nature for use with mechanical stokers, with disastrous results from an economic point of view.

I thoroughly agree with Mr. Thomson's remarks to the effect that the human element in firing marine boilers enters largely into the question of the satisfactory use of any class of bunker coal. This can be easily demonstrated, and, to my mind, a great loss arises through firemen on steamers waiting till their fires are past the highest point of combustion, and then heaping them with green coal, the result being that the heat units developed in the fires are used to an unreasonable extent to bring the green coal to the point of giving off heat itself, with a consequent lowering of the steam pressure. Personally I think that in firing marine boilers, so far as efficiency is concerned, the unalterable motto for firemen should be "fire lightly and frequently."

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Mr. R. J. Butler.

Mr. R. J. BUTLER (Member): Mr. Kahrs' paper more closely approximates to a condensed treatise on the theory of fuel combustion rather than to a paper which can be usefully discussed, and, as he himself admits that his statements are based on already published investigations, its value is to some extent thereby diminished. Broadly, he advocates the purchase of fuel at a rate based upon quality, an ideal condition which, whilst very estimable in itself, is practically an impossibility for ocean-going steamers. It is true that ships' bunkers are not exclusively dealt with in the paper, but, as conditions on land are so totally different from those afloat, the criteria which are adopted by large fuel users ashore lamentably fail when applied to marine work.

Mr. Kahrs' charge of lack of knowledge of the real conditions, and the advantages possible with the purchase price based on the real value, is one which can readily be refuted, many shipowners doing all that is possible, under the varying conditions which are inherent in marine work, to secure the best return for their outlay on bunkers. Mr. Kahrs must be aware that his advocated procedure must at times be jettisoned. Take, for example, a vessel calling for bunkers at an outlying station, say, Ascension, where large quantities of coal of various brands are not stocked. To analyse a sample, not only for calorific value but for moisture, volatile, and ash, would be a work of supererogation where it was either one sort of coal or none at all, or at the best a possible delay in awaiting a consignment that complied with the economic conditions stipulated by Mr. Kahrs. Such a delay might quite conceivably swallow up the whole profits of a voyage, whereas the acceptance of the fuel available, even at a price incommensurate with its value, would enable a successful voyage to be completed.

Mr. Kahrs defines what he calls a new term, boiler heating value, by calorific value of the fuel multiplied by the boiler efficiency, but this term is by no means new, and has long

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been employed in trial and voyage analyses. As he rightly points out, this value will vary with the design, equipment, insulation, draught, conditions of the boiler, skill of stoking, and degree of forcing necessary. The last three are very variable factors depending on the maintenance, personnel, and nature of voyage, so that it would appear to be quite impossible—even if an engineer of highly scientific attainments, provided with all the necessary equipment to enable the various physical and chemical qualities of the available fuels to be determined in the course of a few hours, were carried on every coal-burning steamer—to determine which sort of coal should be purchased to give maximum economy even in the few cases where choice between several qualities was feasible. Mr. Kahrs' engineer would further require to combine the qualities of physicist, chemist, mathematician, and commercial expert, a state of affairs which can hardly be looked for, this side of the millennium, with the present rate of engineers' pay.

On page 269 one of the fuels mentioned has a calorific value of 29,700 B.Th.U's. per lb., but Mr. Kahrs has omitted to state where a fuel of this quality can be obtained. There would certainly not be any difficulty in disposing of the whole output of the colliery where such is mined.

Mr. KAHRS: The question of oil *versus* coal for ship fuel is outside the scope of my paper. I quite agree with Mr. MacNicoll that it would be a great boon if coal could be mechanically handled, and with water-tube boilers I am satisfied that useful stokers for marine purposes already exist, although it seems to be next to impossible to design a satisfactory self-cleaning stoker for Scotch marine boilers. Nor do I think that powdered fuel can at present be satisfactorily used with Scotch marine boilers. I understand it was tried in the south of England a few years ago, with unsatisfactory results. It seems to me that both mechanical stokers and

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Mr. Otto Kahrs.
dust-coal firing should be seriously considered for marine water-tube boilers.

I presume that Mr. Livingstone Jones alludes to single retort types of underfeed stoker. The reasons for their being unpopular on board ship, I think, are several:—

1. The chief fault, I consider, is that the type as installed on board is not self-cleaning. Consequently the hardest job of the stoker has to be performed by hand as before, and no considerable reduction of crew is possible.

2. The arrangement for feeding the stokers is generally very imperfect, and in most cases, if not in all, the coal has to be shovelled by hand into the hoppers, a work which is as fatiguing as ordinary stoking, if not more so, because the coal must be lifted much higher. In such cases, no saving in labour is at all possible. In a fairly large passenger liner fitted with water-tube boilers it was very difficult to maintain the pressure without excessive coal consumption, owing to the stokers being unfamiliar with the wide grates of this type of boiler. Underfeed stokers were introduced with very satisfactory results so far as economy was concerned, but they were quite unpopular with the personnel, owing to the heavy labour connected with keeping the hoppers filled and the stokers cleaned; in consequence of the very restricted space it was next to impossible to devise a satisfactory mechanical solution of the difficulties.

3. Like every other mechanical device, a mechanical stoker needs regular attention—lubrication, upkeep, etc. The engineers, however, were too inclined to disregard the stokers as long as they were operating, and I fear that also the supervision of the operation was usually more or less spasmodic as long as the steam pressure was reasonably maintained, and thus, as the stitch in time was forgotten, the proverbial nine stitches had to be made in harbour later on. This was the real reason of the very high cost of upkeep and the work in harbour mentioned by Mr. Jones.

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Regarding the use of low-temperature coke for bunkers, I think this will prove a great advantage in time, if the produced "semi-coke" can be made sufficiently dense as to not require materially more space in the bunkers than ordinary bunker coal, otherwise I fear it will be greatly handicapped for all except very short trips. Presumably the quality of "semi-coke" would be more suitable for marine purposes, under present conditions, than most of the coals at present used for bunkers, although the ash contents naturally would be considerably higher.

I think that the use of fuel pulverised on shore for bunkers is inadvisable, with the possible exception of relatively short regular routes, by cross-channel vessels, for instance. I hope that Mr. Jones will take the earliest opportunity of placing the working results of the new marine stoker mentioned by him before the Institution.

I quite agree with Mr. Watson that a reliable feed-water meter is highly desirable, and should be installed on all vessels where maximum economy is desired. It must, however, be closely watched, as in any other system, for economy control, if good results are to be obtained. On a certain small passenger boat with water-tube boilers, the coal consumption was liable to be unreasonably high, for the same reason as previously mentioned, namely, the unfamiliarity of the ordinary fireman with the wide grates of the water-tube boiler. The stokers blamed the engine, and the engineers the stokers, and there was continual trouble. The management, who probably either did not know the mechanical stoker or thought it not worth trying, for the reasons mentioned in my reply to Mr. Jones, put in a displacement feed-water meter, and the fault was immediately proved to be with the stoking. To remedy matters, strong instructions were issued, and after some time the stoking appeared to be better, although the results were still far from satisfactory, and much below what was expected from the boiler. Later on exact trials were to be made with another

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vessel before and after fitting superheaters, and for this purpose the feed-water meter was tested at the Technical High School at Trondhjem, as it had been in use for some considerable time. Imagine the astonishment when it was found that it had a considerable constant fault, if my memory is correct, of something like 20 per cent. On further investigation, it turned out that the wheels of the counting mechanism had been tampered with, and the reduction ratio changed by one of the engineers, who presumably had got tired of the continuous complaints of bad stoking, and, like most of his colleagues too, did not relish the exact supervision which feed-water meters made possible.

I cannot agree, however, that the owners should not mind whether their engines use 13½ or 15⅓ lbs. of water per i.h.p. per hour, because, if the maximum economy is to be reached, it will be necessary to save the utmost possible at every single point of the propulsive system. I think Mr. Watson will agree that to obtain a really satisfactory method of buying coal it must be possible to form a close estimate of its value from a sample, and the feed-water meter can only to a certain extent assist in this, owing to the frequent variations of the quality of the coal supplied, see Table I.

With reference to mechanical stokers, I beg to refer Mr. Watson to my reply to Mr. Jones.

Replying to Mr. Hill, perhaps I should probably in some cases have used the word "value" instead of "quality," as I have used the word quality in the meaning of economic value to the owner, and this, I hope I have proved, depends on factors other than the calorific value only.

Regarding the value of trade names, I think that the paper by Mr. Gill, footnote page 255, gives really deciding proofs that the coal supplied according to them may vary much, if Table I cited by me from this paper is not a sufficient proof in itself. Certainly the variations appearing in this table, in my opinion, are in themselves convincing enough proof. It is very

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interesting to learn that owners have already used rational means for deciding on their bunker coal buying. Unfortunately, however, to my knowledge nothing has been published yet on this matter, and, therefore, I was not able to take it into account. Most probably the owners in question have used their boats on regular traffic from home ports, because for the general tramp owner I fear it is next to impossible, under present conditions, to apply the methods. I think Mr. Hill must have misunderstood my statement on page 257, because it was at least my intention to explain that owing to the calorific heating value not being a sufficient measure of coal quality, or more correctly expressed the coal value, for marine purposes, this was the reason why the U.S. Navy did not buy their coal on a calorific heating value basis, although this method is used by all the other U.S.A. Government departments, through the assistance of the U.S.A. Bureau of Mines, but perhaps my power of expression in English has failed me in the paper.

It is possible that I have underestimated the importance of fines, although it is probably correct that the fines produced by breakage during transport are less detrimental to the quality than the fines in the original delivery, as these may be due to inefficient separation of the impurities, for instance, from the roof or slate bands, etc., in the seam. I quite agree with the rest of Mr. Hill's opinions, although I fear that the bomb calorimeter is rather expensive, and outside the capacity of the ordinary marine engineer. The cheaper grades of calorimeters, however, are apt to give wrong results, at least with high volatile coals, and an instrument giving faulty results is, in my opinion, worse than none.

Various experiments, especially in the U.S.A., go to prove that the deterioration of the heating value of coals is greatest in the first few days after mining, and later on is usually fairly small, at least with most kinds of high-grade coal, and probably will not average two per cent. for a year, so that this

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Mr. Otto Kahrs.

risk is not very important. The risk of self-ignition is, of course, something quite different, and is in a class by itself. Obviously the owner becomes earnestly interested in the quality of his bunkers the moment he fully realises that it may seriously affect his profit and loss account. I quite agree that the average tramp boat, and perhaps still more the smaller passenger vessels, are under-boilered—not less than 3·75 square feet of heating surface per sea-going i.h.p. should be installed with natural draught—and this is made still worse by the insufficient draught existing on many vessels. Also too much heating surface has been crowded into certain boilers, thus not giving the evaporation power expected. On all vessels with insufficient draught, certainly everything should be done to improve existing conditions. Taller funnels, larger and better arranged ventilators, air bulkheads, etc., may do much, and if such arrangements do not suffice, artificial draught should be installed. I am inclined to believe that the average boiler efficiency on vessels with natural draught not using Welsh and similar low volatile fuel, is in the vicinity of 55 per cent., which certainly is ridiculously low. I cannot agree, however, that additional crew would be necessary with mechanical stokers or pulverised-coal burning arrangements. On the contrary, I think that, if properly designed and constructed, and with suitable coal-feeding arrangements, considerable reductions in crew will be possible.

I quite agree with Mr. Jockel that it will require very much work and trouble to change the present method of buying bunker coal, but I contend that it will pay well in the end, and should thus be seriously worth while.

Unfortunately, there has not yet been published sufficient authoritative tests of all British coals, but from the data in my possession it seems to me that the calorific values will not be equal, as stated by Mr. Steel, and that the results figured on an ash and moisture free basis will average out somewhat as follows:—

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Coal.	Calories.
Best Welsh Admiralty bunker -	8,600
Best Yorkshire - - - -	8,400
Best Durham - - - -	8,500
Best Scotch - - - -	8,000

Certainly Welsh coal is the most efficient British steam fuel for hand-fired Scotch marine boilers, owing to its volatile contents being practically identical with the optimum referred to on page 269, *et seq*. It must not be forgotten that, although investigation and practical results show certain coals to be the most suitable for marine purposes with hand-fired Scotch boilers, other coals may be the most suitable for steam raising on modern boilers with combustion arrangements which suit the fuel used. Practically any coal can be burnt with satisfactory efficiency if the furnaces are suitable, and thus the whole question results in using the right fuel for the right purpose. When this is generally understood, bunker depots will buy the fuel most suitable for their purposes and to the geographical situation, and in this respect there should not be much risk to the depot managers.

The question of bribery is a difficult one, but if the owner checks his operating results in a reasonable and efficient manner, any bribery would soon be detected and dealt with. Neither is bribery unknown under present conditions, as instances of short weight at overseas bunker depots and the adding of unweighed bags of coal during consumption trials show. Mr. Steel suggests that a start should be made with a guarantee that "the coals are not a mixture varying more than within a certain minimum and maximum percentage of volatiles and a maximum percentage of ash," but fines should at least be included; also the seam and pit from which the coal is mined should be stated.

I omitted to deal with the question of sampling at any length in my paper, as it was already so lengthy, the more

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Mr. Otto Kahrs.

so as there is much information available on this point, and the subject is fairly well understood. But I should like to call the attention of Mr. Thomson to the methods of sampling described by Edward H. Tenney*; perhaps also the U.S.A. Bureau of Mines publications† may be of interest.

It is difficult for me to understand that washed small coal can become much more expensive than large coal with the same ash content and moisture, because it would be very cheap to crush the large coal, and thus supply any desired quantity, the more so as the dust and fines, which may have to be removed by harping, will obtain full price for pulverised-coal firing purposes. I quite agree that it is the practical test which decides, but unfortunately most owners only compare the totals, which are the sums of a large number of more or less independent variables, and, therefore, very often one variable is credited with, or blamed for, something due to quite another variable, and in this special case the reason may besides be quite another, namely, that the coal supposed to be the best, or belong to the best, is in reality wrongly classified, thus the puzzling results mentioned may have quite a natural reason.

I quite agree that the greatest weakness of all is the human element, and the correct way to solve this would obviously be to introduce mechanical stokers, which involve the use of water-tube boilers.

Col. Leslie also refers to the use of sampling. From three to five cores from each car, taken out by ramming tubes through the coal pile, should be quite sufficient for accurate sampling. If the boring tubes were mechanically operated, and the crushing, mixing, and quartering also done automatically by machinery, and the whole sampling outfit placed on a travelling gantry, I think a very large

* "Test Methods for Steam Power Plants," D. van Nostrand Co., New York.

† Bulletins Nos. 11, 41, and 116, and Technical Papers Nos. 76 and 133.

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number of samples could be taken and prepared at a minimum cost, while the part of the gross sample not used for laboratory purposes could be sold for coal-dust firing purposes, thus still further reducing the expenses.

Regarding mechanical stokers, my experience has been that underfeed ones will handle the widest range of coal, but with any mechanical stoker it is, of course, necessary to prevent coal above a certain size entering the stoker hopper. Otherwise the self-cleaning underfeed stoker will certainly burn practically all usual bunker coals with satisfactory efficiency; of course, this means water-tube boilers and reasonably large combustion chambers. The inclined coal-bed surface used on most of the leading makes may not be satisfactory on board ship, however, and this feature may require redesigning, with a view also to reducing the height required for installation, and this would be a decided advantage. The deep ash-pits used in standard U.S.A. practice are very efficient in reducing both the contents of combustible and the temperature of the refuse, but even these might have to be reduced and redesigned considerably to suit ship conditions, especially for small vessels and passenger boats. In this connection, a satisfactory arrangement for sampling and disposing of the refuse may be quite a problem, as the space is very limited, and the handling should be as automatic as possible. When Col. Leslie refers to mechanical stokers being unsuitable for strongly coking coals, I think he refers to stokers of certain types, because there is a number of stokers quite suitable for such coals, although they cannot be used in connection with cylindrical furnaces of, for instance, Scotch or Lancashire boilers.

I quite agree with Col. Leslie that the personnel is the weakest link in the present system, but, as mentioned before, the interest of many engineers in stoking seems to be finished as long as the steam pressure is reasonably maintained, and it must, of course, be admitted that the engine

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Mr. Otto Kahrs.

platform is usually a much more pleasant place than the stokehold.

I do not quite agree with Mr. Butler that there would be any serious difficulty at bunkering stations if the system advocated were introduced generally. Bunkering stations would naturally buy coal on the same conditions, as competition would soon bring them to supply the most suitable fuel. Naturally, if only one quality were available, the system would be valueless, as there would be no choice for the purchaser. I am inclined to believe that Mr. Butler has, to some extent, misunderstood the main purpose of the paper, which was to ascertain by scientific investigation the relative values of the coals produced. It would then be fairly easy to distribute the right coals for the right purposes. The figure 29,700 is obviously an error, and should read 15,300 B.Th.U's.

I wish to thank the contributors to the discussion for their interest in the paper. I am fully aware of the many and important difficulties to be overcome, but the savings possible are certainly worth the trouble involved.

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FAILURE OF METALS BY CREEP.

By Prof. WILLIAM KERR, Ph.D., A.R.T.C.,
Associate Member of the Institution.

12th January, 1926.

THE subject of the mechanical properties of materials has always formed one of the important lines of technical investigation. But within quite recent years the rapid development of new materials, the use of all materials under increasingly severe conditions, advances in testing technique, and the impulses and achievements of scientific study have, by their combined effects, forced the subject to the foremost place in modern technical research. No other line of research to-day carries such a load of responsibility. All branches of engineering—and particularly chemical and power engineering —have presented materials problems of the greatest moment, and await their solution; and possible advances, well within the conception and capacity of engineers, are mainly delayed by these materials difficulties.

Outstanding amongst the several factors impeding advance appears the temperature influence. In fact, the situation at the moment is very largely the outcome of the considerable increases in working temperatures during late years. The steam-turbine builder has long been envious of the probable gains of high steam-pressures and temperatures, and has sought keenly to achieve them. This, reacting also on boiler design, has thrown the materials problems of turbine blading, steam-pipe fittings, and superheater tubes into a new field that has proved conspicuously fruitful of difficulties. The minimum demands of the gas-turbine transcend even the maximum

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requirements of the steam type, and seem, in fact, to be the primary cause of the serious delay in the progress of this newer form of engine. In chemical engineering materials are required for high-pressure high-temperature tubes and containers under conditions that surpass even those of internal-combustion engineering, and seem only possible of satisfaction by the acceptance of a limited life for the materials used. All the various difficulties seem to spring from the high-temperature effects, and it will be easily realised why these effects have been made the subject of intense study.

The direct influence of high temperature in weakening materials is clearly recognised. In general, the strength of any metal is well maintained up to a temperature roughly characteristic of its class, but beyond that the fall of strength is fairly rapid. In determining this strength-temperature relationship the usual procedure of rapid loading up to the point of failure has been invariably adopted, and the curve thereby obtained has been taken as providing the essential information regarding ultimate strength. So long as the rate of loading is not supposed important, the conclusion is logical; but if the rate of loading should enter into the problem, the examination is partial only, and the results are inconclusive. That they show the material in the best light accounts, in many cases, for the attachment shown to the method; but there is now no reason why engineers should be misguided by the results obtained thereby.

The primary neglect of the influence of the time factor in high-temperature testing no doubt arose from its apparent unimportance in the normal cold test. But as high-temperature work developed, it was found that different results were obtained by even small changes in the time under load. And easily the most momentous feature of recent materials testing lies in the striking association of this time factor with temperature. While testing in general had merely been concerned with strength and temperature relationships, there

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had really been a second independent variable, which, ignored by custom in the low-temperature field, was much too prominent to remain long hidden from any search in the higher regions.

The salient feature of the time influence is easily grasped. A stress which, at a given temperature, would not cause fracture under the ordinary condition of quick loading is still potentially destructive, if allowed time. The process of failure is by a "creeping" action, or viscous flow of the material, so slow as to be difficult of detection, but continuous until rupture occurs. The material may endure the imposed stress for a long time, but, if "creep" is established, ultimate disruption is assured.

The word "endurance" has come to be associated with fatigue effects in materials as representing the length of life under repeated cycles of stress, but is strictly as applicable here, where there is a finite life under the action of a steady stress. In fatigue, however, the number of stress cycles is important, apart from the time taken to go through them, so that the time effect is not necessarily the whole effect. In the creep case, however, time may be the only variable, and yet ultimate failure may result. It might be considered a case of "patience" under stress.

And just as patience may be negligible, exhaustible or inexhaustible, so we find corresponding features in the effect considered. At any one temperature there is a stress which the material will not stand at all; a range of stresses taxing its patience to a greater or less extent and ultimately exhausting it; and a lower range so reduced in severity as to leave the material indifferent. It is either a case of immediate loss of "temper," ultimate loss of "temper," or an infinite forbearance.

The engineer responsible for the structural security of designs is frequently rather neglectful of the details of the behaviour of a materials specimen in a full investigation. He pins his

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faith to knowledge of a strength limit, and the operation of a factor of safety. But he does appreciate the importance of limiting values, and must at once detect the significance of the boundary between the conditions producing no ill effects and those ultimately causing failure. This introduces the idea of the "creep limit," *i.e.*, those stress-temperature conditions within which the material is safe from the insidiousness of the creep influence, and beyond which it is not. To the engineer this aspect of the subject is of primary importance, since it necessitates a reduction of the strength limits as commonly established to the creep limits as now defined, a consequent reduction of the range of usefulness of a material in the high-temperature field, and a definite reduction in factors of safety.

These are serious changes, and are hardly yet fully appreciated by engineers. It is the purpose of this paper to examine the experimental work with a view to emphasising the facts regarding creep and creep limits, and in order to bring out the essential points clear of those masses of data in which they are, at times, wrapped. It is a rather fortunate feature of this subject—at the moment—that it is possible to review its main issues within relatively small compass. Its history is short, and can be readily viewed as a whole. Apart from the ease of review, however, which endows the moment with a certain advantage, there is also a certain necessity for this review at the moment. The subject has been examined by a comparatively small band of investigators, independently inspired along rather different lines, and providing data of a fairly varied character that certainly need correlation, and may require criticism. To gain a reasonably general view of the subject a certain amount of this correlation must be undertaken, while, in view of the probable developments in this branch of testing, a little criticism may prove serviceable. We may commence the study of the general aspects of the subject with a consideration of the main experimental work.

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Review of Experimental Work.

In outlining the work of the several experimenters in this field, it should be realised that we are not necessarily studying all aspects of their work. The desire is merely to indicate the mode of search followed, and to show the essential or general contributions made by each investigator. In many cases the

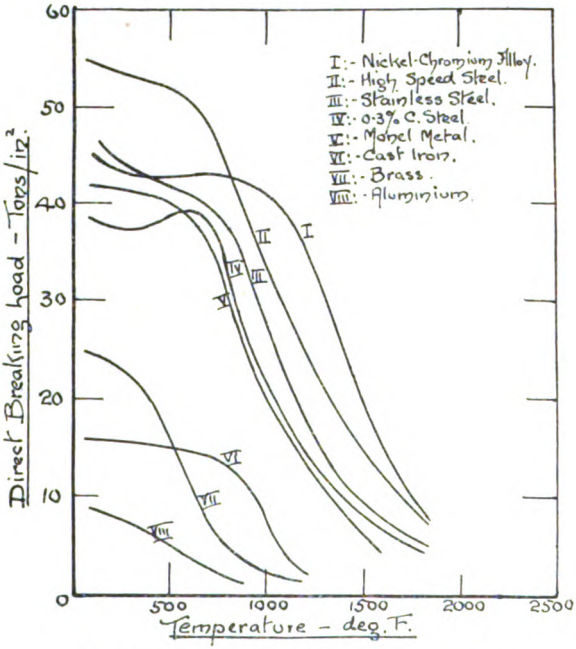

Fig. 1.—Direct Strength-Temperature Curves.

amount of work carried out in an individual research is very great and full of interesting details, but many of these details have no direct bearing on the general problem, and so may be neglected. Some workers have, indeed, been concerned with facts outside the present field of view, and only incidentally provide information requiring notice.

The Direct Strength-Temperature Relation. Ordinary testing at high temperatures has provided full and familiar data

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of the variation of direct strength with temperature. Thus Fig. 1 shows typical curves of the kind for several materials. In general, the forms comprise a level of well-maintained strength over a moderate temperature range, a range of rapidly falling strength, and a useless range of negligible strength. Such curves are easily determined for any material by simply heating the specimen to the required temperature, perhaps soaking it at this temperature for a period, and then directly breaking it.

The length of time at the temperature before actually loading up is in no sense a time effect as we require to recognise it in our subject. The stress must act during the time considered. As the length of time allowed under stress increases, a smaller and smaller stress will suffice to cause fracture by slow and continuous "give" of the specimen, until, for a length of life of several thousand hours, the stress curves of Fig. 1 have to be very drastically sheared down to represent the real ultimate strengths. The cohesive power of the material may be broken by violent loading over a brief interval, or by a much lighter action over a long period. It is information regarding the less strenuous and longer life that is sought.

Chevenard's Preliminary Work on Creep. The first direct investigator in the creep field appears to have been Prof. P. Chevenard, of the École National des Mines de St. Étienne, France. His studies* were to some extent prompted by a declaration by Prof. Bouasse regarding the viscosity of metals in the higher temperature ranges, but were largely the outcome of a necessity to classify certain ordinary and special steels in order of merit as regards rigidity under high-temperature influences. The initial conditions of his materials were affected by heat treatment, the study of which was part of the

* "Sur la viscosité des aciers aux températures élevées." Comptes Rendus, July-Dec., 1919, p. 712.

"Alliages de nickel conservant leur rigidité dans un domaine étendu de température." Comptes Rendus, July-Dec., 1922, p. 486.

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investigation, but we are only concerned with the results of the examination of the viscous phenomena.

A wire of the material was subject to definite loading at a chosen temperature, and the gradual extension under the load was recorded photographically. Different loads and various temperatures were adopted, but the time under test was comparatively short—a few hours only—and the total extensions recorded were only of the order of a few per cent. This was considered sufficient for the purpose in view, but Chevenard

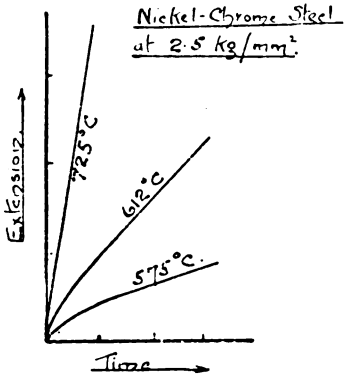

Fig. 2.—Creep Curves (Chevenard).

realised that more prolonged tests were necessary for the full examination of the problem.

The type of extension, or creep, curves obtained are as sketched in Fig. 2. There is a fairly rapid elongation at first which tends, however, to settle down to an apparently steady rate of flow. Chevenard assumes this final rate to be characteristic of the conditions and, for different temperatures and stresses, measures these apparently steady rates. By plotting the results on a base of temperature, such curves as are indicated by Fig. 3 are derived.

The outstanding feature here is the obvious tendency for the curve at each load to run into the zero creep line at some

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limiting temperature; and, although the actual conjunction with the axis is not defined exactly by the experimental data, it seems possible to fix the probable temperature value with a fair approximation. Thus Chevenard, by an ingenuous and rapid method, obtained a clear demonstration of the enormous importance of temperature, and evidence of the existence of a practical creep limit. The fact that the material may be more definitely weakened by a small temperature increment

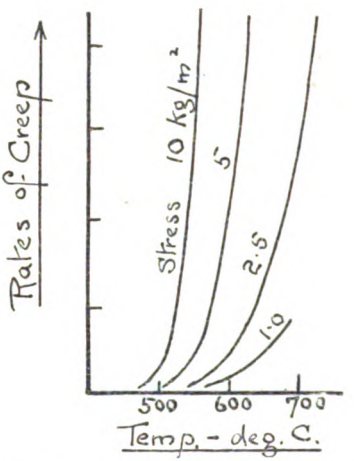

Fig. 3.—Creep Rate Curves (Chevenard).

than by a large percentage stress increase, is clearly brought out by these curves.

It will be clear, of course, that to be fully conclusive regarding creep limits very lengthy tests are required. As the rate of flow decreases, the time to produce fracture becomes exceedingly great. It is, therefore, as difficult to establish creep limits directly and explicitly as it is to establish fatigue limits. The extreme care and excessive time involved in a complete examination will largely prevent such studies being freely undertaken, and will necessitate the development of methods capable of showing the essential creep limits without undue

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expenditure of time. Chevenard's method would appear to be a fairly legitimate procedure of the kind; but the next experimenter on the subject has seen the problem with a full comprehension, and tackled it with a patience that is noteworthy.

Dickenson's Investigations. The importance of the lengthy work carried out by Mr. J. H. S. Dickenson, of the Vickers Research Laboratories, on the creep of various steels can hardly be overestimated. The investigation* appears to have originated in the necessity to examine the behaviour of a material proposed for the catalyst tubes of a synthetic ammonia process. The tubes in actual practice were to be subject to very high pressures at a temperature of about 1,100 degrees F., and the experimental specimens were subject to roughly corresponding conditions. The investigation thus arising out of a manufacturing problem developed, however, into a systematic study of creep effects in various steels.

Again the experimental procedure is of an extremely simple type. The specimen is loaded through a simple lever arrangement, and heated by an electric furnace, the temperature being determined by a thermo-couple attached to the centre of the specimen. The load was kept constant in all tests at 8·5 tons per square inch. On any one test the temperature was maintained within a limited range of variation for the length of time necessary to cause fracture—day and night for months if necessary—or sufficient to show that ultimate failure was unlikely. The extension of the specimen under its constant load was recorded daily.

The data from these tests, then, show the duration of life of each material tested, under a constant load of 8·5 tons per square inch and at different temperatures, along with the progressive stretching during the period. Thus Fig. 4 shows, as examples, the life in hours at different temperatures of a 14·7 per cent. chromium steel and a nickel-chromium alloy; while

* "The Flow of Steels at a Red Heat." Journ. Iron and Steel Institute, Sept. 6, 1922.

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Fig. 5 presents the extension graphs for the former. It will be observed from Fig. 4 that while the temperature-duration curves appear to be tending to a limit, no limit is definitely marked. The curve for the alloy, for example, is still slowly falling even at 6,000 hours. At the same time it must be remarked that lower temperatures than those indicated by the

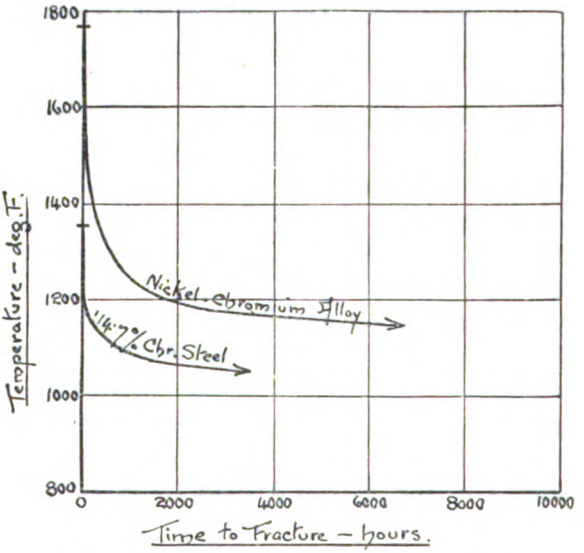

Fig. 4.—Temperature-Duration Curves (Dickenson).

flat parts of the curves failed to cause fracture; and a specimen of the nickel-chromium alloy at an average temperature of about 1,065 degrees F. was estimated to have carried the load for over 100,000 hours without fracture.

The evidence of the facts portrayed by Fig. 4, and of the unbroken specimens which it does not include, make the assumption of a real limiting temperature quite rational. There is a certain conflict of view between the metallurgist and the engineer on a point like this. The former is loath to admit a limit effect until he has a physical reason for it, while the

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latter, to justify and guide his methods of design, will create a limit when he has much less evidence than in the present case. As things are, the question is really one of the interpretation of a curve form. Thus Dickenson has plotted the temperatures of Fig. 4 against the logarithms of the corresponding durations, and obtains a straight line. The direct deduction from this is, obviously, that the 8·5-ton load could ultimately

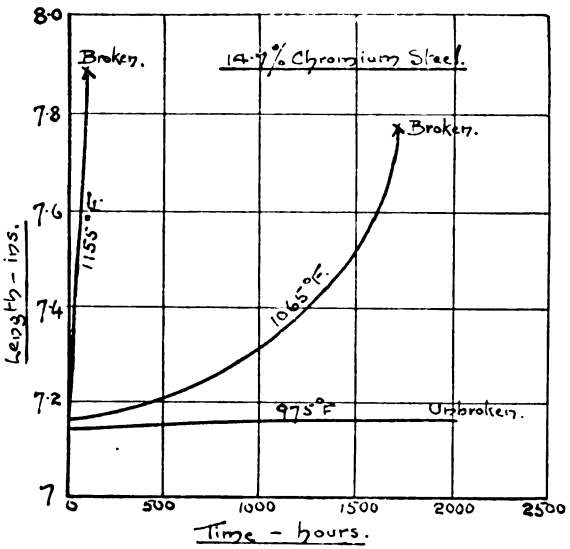

Fig. 5.—Creep Curves (Dickenson).

break a cold specimen. The time necessary, however, would be of such a magnitude that a geological era would appear but a fleeting instant in comparison.

But logarithmic plotting of such results is simply equivalent to assuming the curve form. It is perhaps permissible to intrude here with the suggestion that logarithmic plotting can sometimes be very misleading. The virtues of a process whereby a curve of awkward shape is flattened to a simpler form tends frequently to blind observation of the main char-

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acteristic of the parent curve. It would appear to be so in the present instance. It is certainly equally valid to interpret the curve type from the direct plot, and say, for example, that the temperature-duration relation is hyperbolic. We should then at once have a limit value introduced—the asymptote to the curve. And it may be contended that if Fig. 4 conveys any one impression definitely, it is of the genuineness of this fact.

This matter has been somewhat laboured, but the form of the curves in Fig. 4 is of critical moment in our subsequent study. Meantime, it may be accepted that Figs. 4 and 5 represent, typically and concisely, the nature and outcome of Dickenson's work.

Dickenson also first used the method of regularly increasing temperature steps under the steady load, with observation of the final temperature at which fracture occurred, and measurement of the progressive elongation. The details of this, however, need not be entered into, as a later investigator applied the method rather more extensively, and provides more directly the slight information available under this head.

Lea's Creep Tests. Prof. F. C. Lea has contributed* largely to this subject. His line of attack falls between that of Dickenson and that of Chevenard. Employing a method of examination akin to that of the latter, he carries his observations over much longer periods, without, however, reaching the extreme times involved in Dickenson's work.

A standard testing machine was used in this case, with a special extensometer for creep measurement, and a remarkable variety of creep records were obtained. Many of these are of a partial nature, and represent tentative efforts only. They help to throw some additional light on the phenomena, and, in the aggregate, represent very extensive labours, but are mainly notable as marking out the development of the research

* "Effect of Low and High Temperatures on Materials." Proc. Inst. of Mechanical Engineers, Dec., 1924.

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towards the technique finally adopted, and by means of which the main results were derived.

The outstanding general feature of Lea's discussion lies in the explicit recognition and definition of what we have called the creep limit. This is called the "temperature-viscosity stress," and, for various steels, values are actually tabulated from which such a curve as that shown by the full line in

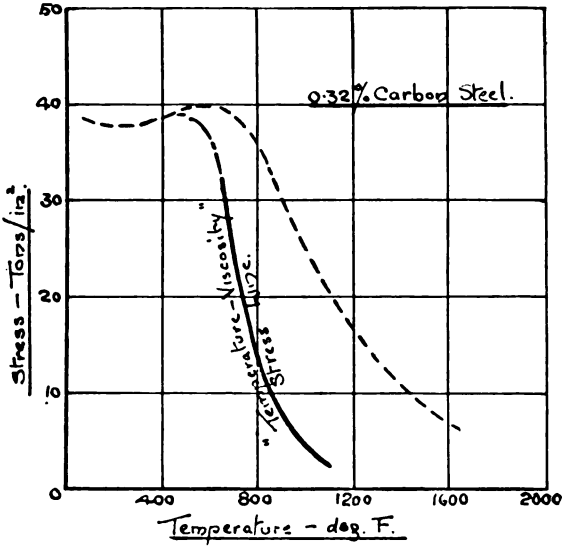

Fig. 6.—Creep Limit Curve (Lea).

Fig. 6 can be obtained. The dotted curve in Fig. 6 roughly represents the appropriate quick break conditions. Lea's data, therefore, provide some indication of the general run of the boundary line between the creep and non-creep fields, and, consequently, extend very definitely the range of data previously available.

Lea is also the only investigator who has examined the increase of extension with time at normal temperatures. Curves are plotted for a mild steel at room temperature, for

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example, which are rather surprising in extent, and show growth over an hour or so at practically all stresses. But so long as the stress at this low temperature is within the ultimate value as ordinarily determined, the extension finally ceases. The obvious conclusion is that at low temperatures the normal breaking strength and the creep limit are nearly coincident. Hence the curve of Fig. 6, as actually defined by Lea's stated values, might be produced as indicated by the dotted extension to cover the general fact of this low-temperature case also, and so provides the most concise view of the main results.

The details of these experiments are rich in interest and variety of method. Thus one procedure used was to increase the load step by step as the creep due to the previous load ceased, so reaching a breaking stress by a "creep and halt" process. By such a method, carried out slowly at ordinary temperatures, a specimen was ultimately made to carry a load in excess of what would have broken it in a direct test. This seems merely to illustrate strain hardening in a somewhat new way; but it will be understood that similar effects are unlikely to show in the high-temperature field, since complete annealing will take place in any prolonged test of the kind.

But these various processes were of a preliminary nature, and Lea was ultimately led to the method of searching for the stress at which creep ultimately ceased. His final procedure for the determination of the limit lay in plotting the creep rate in inches per hour against the stress for different temperatures, and taking the value at which the curves met the zero creep line. The method, therefore, is practically identical in principle with that used by Chevenard, but the examination is made over much more extensive time ranges, and involves the observation of more minute creep rates, with, consequently, a much more exact demarcation of the limiting values.

Fahrenwald's Discussion. A short discussion of this subject showing forms in a general and interesting fashion has been

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given by Mr. F. A. Fahrenwald.* This author states that his experience with metals under stress for long periods provides strong arguments against the existence of any real elastic limit, and supports the idea of viscous flow under stress at all temperatures. This is much the same thing as saying there is no real creep limit, but a practical limit is diagrammatically expressed. It is the peculiar form given to this limit that leads to its inclusion in this collection of general data, as, although of much interest, the paper is not backed by experimental work, and merely summarises experiences without detailing their nature or extent.

Fahrenwald's general descriptive diagram is somewhat as sketched in Fig. 7. Where we have, so far, only been considering two fields on the strength-temperature chart, a third now appears. The original paper enunciates the facts thus: "With sustained loads for periods covering months, and in many cases years, it is found that with stresses up to CBB—or, at quite low temperatures for heat-treated steels up to BBB—no, or very little, deformation occurs, but with higher stresses appreciable flow takes place; hence the time factor has reduced the curve AA to CBB."

The shape of this diagram is perhaps exaggerated, but a somewhat similar idea is disclosed in the actual curves put forward for certain materials. The curve that separates specific cases in which deformation took place within a year from those in which no change occurred, determines what amounts to, and is taken as representing, a practical creep limit. Such curves embody explicit facts, but they are of a statistical rather than an experimental order. It is claimed that the results given are the concise expression of the facts of hundreds of cases, and that they have been checked by long time laboratory tests.

The new subdivision of the field that enters into Fig. 7 is

* "Some Principles Underlying the Successful Use of Metals at High Temperatures." Proc. American Soc. for Testing Materials, Vol. 24, 1924.

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at variance with Lea's tests, and so far there is no direct experimental evidence in its favour. Roughly put, it amounts to saying that any stress above the elastic limit may produce failure by creep even at low temperatures. But Lea's tests and results are against this, and that investigator's examination of creep at low temperature is fairly conclusive. In the

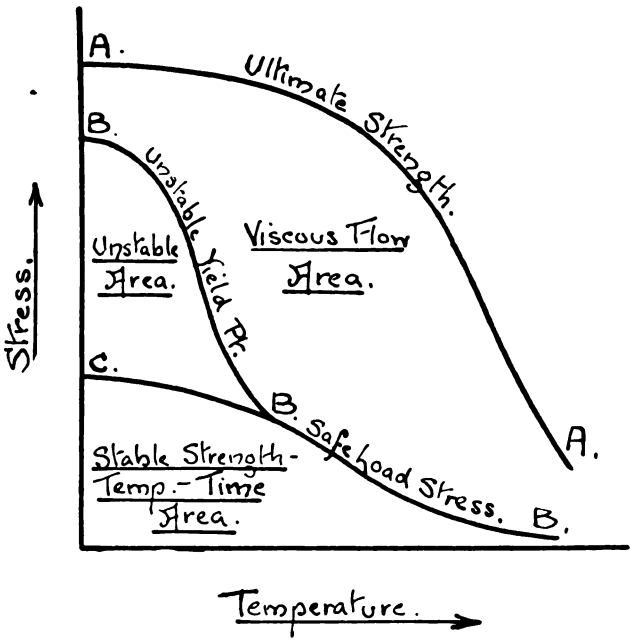

Fig. 7.—Stable and Unstable Fields (Fahrenwald).

absence of the explicit facts in support of this new contention, the greater weight must necessarily be given to the contrary findings of direct experiment. It might, indeed, be submitted that Fahrenwald has allowed himself to be unduly impressed by deformation without discriminating between normal plastic deformation and truly continuous creep. It is possible also that the idea of a factor of safety may have influenced the

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position of the limiting curve, as the relative extent of the viscous flow field in Fig. 7 seems unnecessarily large.

Brown's Investigations on Non-Ferrous Metals. All the investigations already dealt with have been concerned with steels, probably because the ferrous metals are easily the most important in the high-temperature field. But it is natural to ask if similar peculiarities are exhibited by the non-ferrous groups, which, while not employed in the most severe stress and temperature conditions, are still judged by means of the figures provided by the ordinary direct test. If the same phenomenon shows itself with these, it becomes equally necessary to examine the corresponding creep limits, so that the viscous field may be avoided. If the effect should be relatively as great as for steels, it seems probable that a large percentage of the non-ferrous materials in actual use are under conditions that appertain to the danger zone.

The main question is answered by the experiments of Mr. J. S. Brown,* who has examined the influence of the time factor on the breaking strength of a variety of non-ferrous metals. Again we have the simple type of testing machine typical of this class of work. The specimen is loaded direct—by a spring in this case—and is heated by an electric furnace, with temperate measurement by thermo-couple. No arrangement is made for recording or observing extension, and it seems clear that the time effect was recognised and explored directly as such.

Actually it would seem that Brown fully realised the opposing characteristics of any complete line of inquiry into time effects and the requirements of practical testing. He has obviously been largely concerned with the development of a procedure that would cut down the time necessary, and hence has evolved a rather new and interesting mode of search for the genuine ultimate strength over long periods. For any assumed

* "The Influence of the Time Factor on Tensile Tests conducted at Elevated Temperatures." Journ. Inst. of Metals, Sept., 1925.

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temperature the loading was increased by more or less regular steps until failure occurred, the investigator appearing finally to believe that a loading increment of one ton per square inch per day was satisfactory and sufficient.

Fig. 8 shows one typical graph—for monel metal—from Brown's series, which also contains curves for brass, gun-

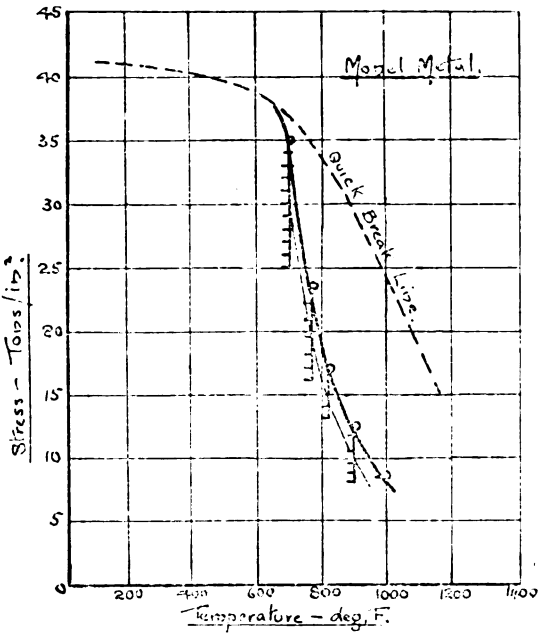

Fig. 8.—Ultimate Strength Curve by Progressive Loading (Brown).

metal, phosphor-bronze, and aluminium. The attempt to define the full range of the limiting curve by direct experiment is notable, as no other investigator has envisaged the complete range quite so fully. The vertical lines leading upwards to the circles denoting fracture indicate the progressive loading, the cross bars on these lines marking the separate steps. Generally, each bar means a period of 24 hours, but here and there longer periods were allowed.

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The full-line curve of Fig. 8, submitted by the experimenter as representative of the true strength of the material, passes through the actual points of fracture. The real procedure, however, amounts to passing upwards into the creep field across the boundary line, and, consequently, the acceptance of the curve as the limiting curve for the material tacitly assumes that the method does not carry the point far into this field. In the absence of actual extension measurements, there is no direct evidence from which a hint as to the amount of penetration might be derived; but it will be clear that, if the effect is really a creep effect, the rate of loading will, to some extent, control it.

It will be recalled that Lea employed the increasing load method, but only in a tentative and preliminary fashion. Brown, on the other hand, has conceived and employed it as a main line of attack. If, however, a legitimate procedure in this line of work be defined as one that gives, or approximates to, the creep limit, it would appear necessary to know the relation between the curve obtained by this method and the true limiting curve. This matter will be returned to later.

Ingall's Progressive Temperature Tests. The secondary method used to some extent by Dickenson, namely, a steady rate of temperature rise at constant load, has been largely employed by Dr. D. H. Ingall in certain experimental studies of various metals. This work is described in two papers,* but is only somewhat indirectly connected with the present theme, and the essential matter for our consideration may be briefly presented.

Wires of the various materials—copper, silver, aluminium, etc.—were subject to constant loads, with the temperature

* "The Relationship between Tensile Strength, Temperature, and Cold Work in some Pure Metals and Single Solid Solutions." Journ. Inst. of Metals, Sept., 1924.

"The High Temperature Tensile Curve." Journ. Inst. of Metals, Sept., 1925.

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increasing at a steady prearranged rate per minute, the temperature at which fracture occurred being noted. The data so derived for any one metal permit the plotting of a strength-temperature curve which defines the ultimate temperature reached as a function of the stress, for the rate of temperature increase used. The records show that for the metals used the curve is in two distinct parts. For the lower temperature range it is a straight line. In the higher temperature ranges the curve falls more rapidly, but is of a curved form, which is further complicated by peculiar loop formations. The investigator is largely concerned with these loops, but they hardly enter into the subject.

Ingall supposes, however, that the termination of the straight line portion marks the temperature limit above which the material is liable to fail with time. It is conceived that at the higher temperatures the metal behaves as if partly crystalline and partly viscous, and that the curved high-temperature line denotes the conditions in which viscous flow may occur. Hence the straight line portion marks the range of sound mechanical use. It will be seen that the conclusion really amounts to the statement that the creep limit is a temperature limit pure and simple. In a practical sense Brown's curves might be taken as showing much the same idea, since the fall is very rapid, but such a conclusion can hardly be held as borne out by experimental work on creep generally. There is no obvious reason why this view should be taken, and, moreover, it is not at all clear that the method of testing is competent to define any limiting creep value.

In the second investigation, Ingall carries the matter further by means of an important development in his procedure. He now employs two or three different rates of heating on the same material, and determines the straight line portions of the strength-temperature curves for each rate. The curves are found to be distinct. Thus Fig. 9 shows the results for three rates of heating with copper, and it will be seen that the slower

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rates give lower ultimate values. The lines are nearly parallel, and definitely apart. Such a result would appear to reflect somewhat on the line of argument previously adopted. It may be looked upon, from our point of view, as the essential outcome of this procedure, and will receive due attention later.

N.P.L. Researches. The results of a very careful investigation of the limiting creep values for a nickel-chromium alloy

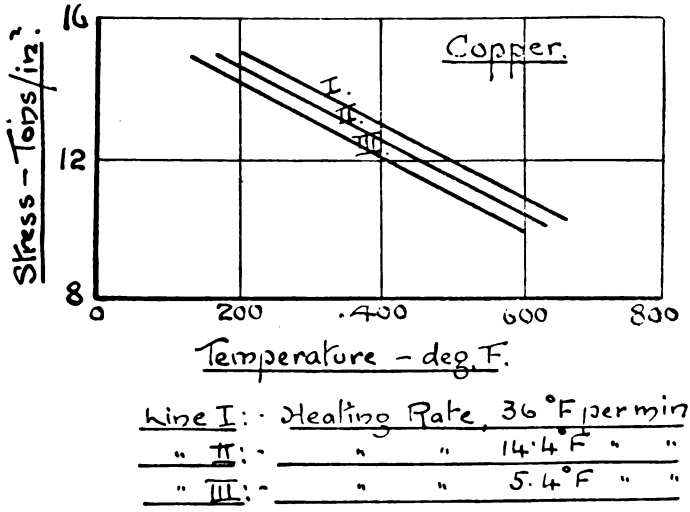

Fig. 9.—Strength Curves at Different Heating Rates (Ingall).

carried out at the National Physical Laboratory, have recently been published in a paper* by Messrs. Tapsell and Bradley. The apparatus used was similar in principle to that of Dickenson, but special methods were employed to keep the temperature variation within a few degrees of the required mean. The creep was read daily by extensometer, and a high degree of accuracy would seem to have been attained in tests extending over very lengthy periods.

* "Mechanical Tests at High Temperatures on a Non-Ferrous Alloy of Nickel and Chromium." Engineering, Nov. 13, 20, and Dec. 11, 1925.

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The procedure for the determination of the limiting stress values really amounted to a straightforward search for the maximum stress at each chosen temperature which gave no creep beyond the first phases of the test. This stress was gradually approached through a series of specimens from higher values which gave fairly quick failure. The whole process is closely akin to that of Dickenson, but the search is along a line of constant temperature instead of constant stress. A more accurate and more explicit determination of the limiting value is achieved, but examination is mainly concentrated on the inner regions of the creep field.

The published curve is for the partial temperature range 930 degrees F. – 1,470 degrees F. At the former value the creep limit is 24 tons per square inch, while the direct test gave 45 tons per square inch. At the higher temperature the limit is only 1·9 tons per square inch, as against the apparent ultimate strength of 18 tons per square inch. While the curve defined by these tests is the most accurate limiting creep stress curve so far determined for any material, the general features of the subject already discussed serve to cover its actual form, and it need not be reproduced here.

Analysis of the Main Experimental Facts.

An outline has been given of all the leading experimental facts of this subject; and although the investigators have been comparatively few in number, they have ranged freely over the whole field, and gathered data that are rich in variety, but somewhat unrelated in form and order.

Thus Chevenard bases ideas of a creep limit on the extrapolation of rates of creep after only a very limited period of time. Dickenson attacks the matter fundamentally, and demonstrates the progressive increase in duration of life under reducing temperatures, but at one load only. Lea examines a variety of methods and the miscellaneous data which they provide, but eventually falls back on a somewhat improved

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form of the Chevenard procedure. Fahrenwald introduces new doubts, and rather sweepingly extends the creep field, but produces no explicit evidence in support thereof. Brown employs the special procedure of a regularly stepped loading, and marks the ultimate load so reached as the practical limit, but records no extension data. Ingall uses progressive temperature steps, and marks the termination of a straight line relationship between load and temperature as the effective creep limit, but his own more elaborate procedure hardly supports this simple assumption. The National Physical Laboratory workers provide some exceptional information, but only on one material over a partial temperature range.

It would be difficult to conceive a situation at once so creditable to the several investigators and so unsatisfactory to the subject. It is clear that a good deal of work remains to be done, and will be done, on this subject in the near future. And the question naturally arises as to whether it is possible to discuss the general facts of experiment in such a way as to provide some basis of correlation, or so to examine them that their legitimacy, agreement, and connection are demonstrated.

Materials testing in general is prolific in the output of purely empirical data. From the nature of the subject that is, of course, to be expected; but it is well at times to scan new masses of data for some hint of order. In engineering design the most concise expression of fact is always sought, and will be used to the exclusion of much more accurate data lengthily enumerated in diffuse sources. In the use of scientific facts in aid of design, brevity of grouping and economy of thought are essential, and can only be achieved by the drastic pruning of data collections. The ultimate aim is that rigorous and comprehensive theoretical analysis which illuminates and displaces the compilations of experimental observation in the process of explaining them. In the subject of materials, that general treatment is almost beyond hope; but below it there is

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what may be termed experimental analysis, which performs the function of establishing a useful order amongst heterogeneous data, and of guiding investigation along regulated lines towards the completion of essential information. It is not concerned with reasons, but only with order; and it may be contended that this humbler form of analysis is too much ignored in the examination of materials test data, and its importance as a means of reduction, expression, and guidance is too little appreciated. The diffuse condition of this comparatively new experimental subject of the creep of metals is a case in point, and it is of advantage to examine how far the methods of simple analysis will go towards reducing the varied experimental records to their most concise expression.

The Temperature-Duration Relationship. In the present problem we may start with the assumption that there is a real creep limit, such that for any loading there is a temperature below which viscous failure is impossible, and above which failure occurs in a finite time depending on the temperature value. It is only necessary to look at such curves as those in Fig. 4 to recognise that the observation of the most direct and fundamental experiments on creep can be so read. If, then, we have to introduce a real limiting temperature, the form of the temperature-duration curve might be taken as hyperbolic. Reference has already been made to the process of logarithmic plotting, and it is now submitted that the procedure here proposed is more rational than any other, in that the most notable feature of the subject, and the outstanding characteristic of these curves, are at once, and most simply, introduced.

Consider the curve form sketched in Fig. 10. This generalises the hyperbolic form of the temperature-duration curve, and its asymptote—shown by T_c—marks the creep limit temperature. Again, the starting point of the curve—at T_o—is taken for a test of duration k hours. This is for the purpose of avoiding that range of very fast testing of the "minute and seconds" order in which many effects are introduced that can hardly be

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expected to fall on a curve shape expressing viscous flow influences. In other words, it would appear necessary to debar those temperatures of failure at which the failure is extremely rapid.

With very rapid loading the temperature values would seem rather useless, unless they can be related to the loading speed with high accuracy. Thus, for his nickel-chromium alloy, Dickenson gives the following values for a loading of 8·5 tons per square inch:—

Time.	Temperature.
3 minutes	1,645 degrees F.
1 minute	1,695 ,, ,,
6 seconds	1,770 ,, ,,

The temperature variation here is extraordinarily wide, and it looks as though very remarkable limits can be obtained by forcing the pace of testing. It is difficult to believe, however, that the same values would be obtained every time a fast test was repeated; and it will be admitted that very rapid conditions could hardly act as a serviceable basis from which to measure the influence of time.

It may be taken, then, that a basis test period is required, and k in Fig. 10 represents this period. For simplicity we may think of it as, say, a one-hour test, but something less than this would serve equally well. Any better result than is given by the basis test may be considered adventitious, and in no wise representative of any sustained strength of the material.

The general form of expression that will contain the essential features shown in Fig. 10 is

$$H - k = (aH + b)(T_o - T) \quad - \quad - \quad - \quad (1)$$

or, if $t = T_o - T$, we obtain

$$H = \frac{bt + k}{1 - at} \quad - \quad - \quad - \quad - \quad (2)$$

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for the length of life corresponding to the given range t. In this a and b are constants for the curve form, and since this form is for a constant-stress condition, it follows that a and b are necessarily functions of the stress; or, alternatively, since T_o is the basis breaking temperature, a and b will vary with T_o.

At present it should be realised that (2) contains all the temperature-time features at constant stress as obtained by Dickenson, and, with explicit a and b values, (2) could give these results in their entirety.

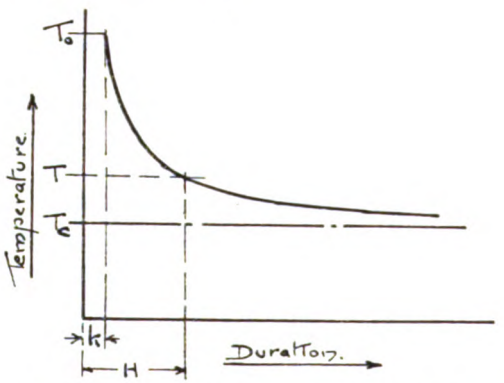

Fig. 10.—The Hyperbolic Temperature-Duration Curve.

It is obvious from the form of (1) that a plot of $\frac{(H-k)}{(T_o-T)}$ against H should give a straight line. Taking the three-minute test on Dickenson's nickel-chromium as the basis, and using the following data from the original tests,

Time.	Temperature T.	T_o - T.
3 minutes	1,645 degrees F.	—
273 hours	1,355 ,, ,,	290
901 ,,	1,245 ,, ,,	400
6,041 ,,	1,155 ,, ,,	490

the graph shown in Fig. 11 is obtained. The three points thus available fall on a straight line as required, and while this is hardly a comprehensive check, it is practically the only case—

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excepting a nickel-chromium steel—in Dickenson's series that provides even this short sequence of values. If the fastest test (six seconds) were taken as the basis, we should still obtain a straight line through the three long period values of $\frac{H-k}{T_o-T}$, but the quick tests would fall below the line as points on the short intercept on the vertical axis. This shows a distinction between the fast and slow tests, and prompts the assumption of a basis period; but it will also be

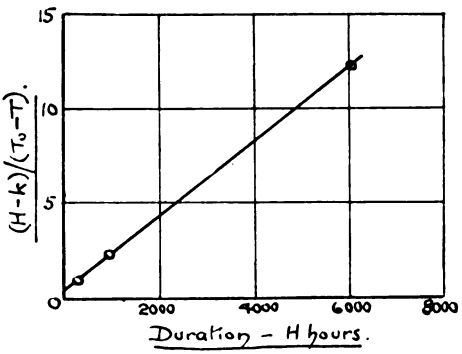

Fig. 11.—The Straight Line Law $(H-k)/(T_o-T)=aH+b$ illustrated by Nickel-Chromium Alloy Data.

noticed that even the short period of three minutes appears sufficient for this.

By examination of (2), it is seen that H becomes infinite for $t=\frac{1}{a}$. This occurs when $T=T_c$. Hence

$$T_o-T_c=t_c=\frac{1}{a},$$

and the constant a is merely the reciprocal of the temperature range in the viscous field at constant stress, within which failure is possible in some time greater than k. This gives a very simple method of introducing the creep range and, if a were expressed in terms of stress, the creep field would be fully defined.

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The Viscous Extension. We pass next to the consideration of the extension, and again attention is first confined to the fundamental constant-stress long-duration tests by Dickenson.

The essential facts are of the type shown by Fig. 5. The notable features of the curves therein are (1) that the creep rate increases as the extension increases, and (2) the time is greatly reduced and the extension much more rapid as the temperature increases. These general features can only be derived from Dickenson's tests, as most other extension data are only of a partial nature, and give an impression of steady creep rates that is hardly supported by the full-range curves.

The noticed characteristics suggest exponential forms, and we may, therefore, suppose that the extension-time relationship on the duration tests is expressible by some such form as

$$cu = e^{r \cdot h} - 1 \quad - \quad - \quad - \quad - \quad (3)$$

in which u is the extension, h is time, and e is the Naperian log. base. The coefficient c depends on the curve shape. The index r is a constant for any constant stress constant temperature conditions. Hence, under steady load, change of temperature will be reflected by change of r. It is seen from (3) that when $h = o$, $u = o$: and since

$$c \cdot \frac{du}{dh} = r \cdot e^{r \cdot h}$$

the rate of creep varies rapidly with temperature, while under any given steady conditions it increases according to the compound interest law. This meets the facts of the case in a general way.

Actually in (3) the simplest expression reasonably adequate to the facts is taken. For more exact agreement, a more complicated form might be necessary. But the data are rather imperfect and rough, and in such a study as this it is much more important to embody the main features of a set of results than to express each curve with meticulous accuracy. At the same time the coefficient c in (3) exercises considerable power

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over the curve shape, and may be adjusted without influencing general conclusions to any extent; but it is on the whole desirable that c should be kept constant for constant stress conditions.

The essential time to failure is already expressed by (2). If the value of the extension at failure is $\bar{u}$ for any given stress-temperature condition at which the duration is H, then

$$c.\bar{u} = e^{r.H} - 1,$$

and hence

$$\log_e(c\bar{u}+1) = r\,.\,H.$$

Since the value of H is given generally by (2), we get

$$r = \left(\frac{1-at}{bt+k}\right)\log_e(c\bar{u}+1) \quad - \quad - \quad - \quad (4)$$

and consequently, by substitution in the logarithmic form of (3), there follows

$$\frac{\log_e(cu+1)}{\log_e(c\bar{u}+1)} = \left(\frac{1-at}{bt+k}\right)h. \quad - \quad - \quad - \quad (5)$$

This does not, of course, give the actual extension explicitly; it only defines it in terms of the failure extension, and this latter would have to be known to determine the extension after any time h. It might be reasonable to assume this a function of the temperature only, and take the extension for the basis period test as defining it. In this way we could build up a consistent scheme in which the fundamentals of time, temperature, and extension in creep are connected with the corresponding values for the short test.

As it stands, equation (5) only expresses the case for constant loading, since that is the only case so far considered, or, in fact, completely covered by fundamental investigation. But the coefficients a, b, and c can vary with the loading, and if the variations were incorporated in (2) and (5) these expressions would be general.

It will be noticed from (5) that when $t = t_c = \frac{1}{a}$ there will be no extension; while for $t = 0$, u reaches $\bar{u}$ in time k. These

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are merely the extension characteristics corresponding to the main features of (2), and are automatically introduced by making $\bar{u}$ correspond to H.

In Fig. 12, curves of u against h are plotted for the conditions defined by the following:—

$$\bar{u} = 0{\cdot}4 \text{ ins.}, \quad a = 0{\cdot}00197, \quad b = 0{\cdot}41, \quad c = 25.$$

Using these in equation (5), and taking values of t such that, with a quick break temperature of $T_o = 1{,}645$ degrees, the test temperatures marked on the full-line curves are obtained; the curves themselves are easily established. The conditions stated have been taken roughly to correspond with Dickenson's nickel-chromium alloy, and his actual extension curves are shown dotted alongside the calculated shapes. The actual extensions at fracture are seen to be irregular as determined by experiment, and yet the use of a constant value of $\bar{u}$ does not seriously upset the respective total times. By varying $\bar{u}$ and c as necessary the separate curves could have been met with considerable accuracy, but any advantage so gained is trifling in comparison with the simplicity of the process used. It may be noticed that with $c = 25$ and u in inches we have practically the same conditions as with $c = 1$ and u in millimetres, and hence the c could be deleted if the extensions were measured in millimetres. This is a feature of several of Dickenson's curves, but it is better that c should be retained in general.

It will be appreciated, then, that the extension relation (5) is fairly competent to express the facts as determined by constant-stress long-duration tests. The assumption of a constant failure extension is not fully supported by the actual case portrayed in Fig. 12, but it is in some other cases. This assumption is, however, not absolutely essential; it is made for the purpose of simplification, and on the whole is as convincing as the somewhat erratic data available.

Equation (5), however, is hardly complete as a picture of the facts of creep. Chevenard's work, and Lea's particularly,

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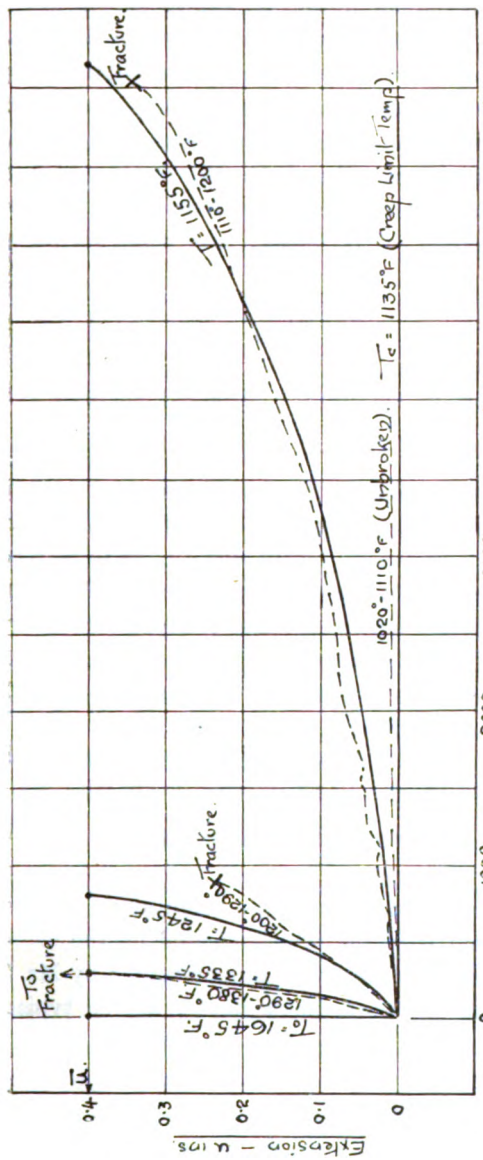

Fig. 12.—Exponential Creep Curves—Equation (5)—illustrated by Nickel-Chromium Alloy Data.

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show that, in its small initial stages, the creep is not of an exponential type. Whether viscous flow will continue to ultimate failure or not, a certain initial amount apparently occurs. When the conditions are actually clear of the continuous creep field, this initial extension slows down to zero rate. It will be recalled that both Chevenard and Lea search for the maximum temperature or stress that still gives this ultimate zero creep. The initial creep could, if required, be expressed by

$$c \cdot u^1 = \frac{h}{mh+n} \quad - \quad - \quad - \quad (6)$$

which shows, as h increases, a tendency towards a limiting value for u^1 of $\frac{1}{c \cdot m}$.

This value of u^1 would, of course, be small in relation to $\bar{u}$ at fracture, but in any consideration of initial effects some such quantity as is denoted by (6) would have to be recognised. The real evidence regarding it is rather scanty, but, judging from Lea's investigations, it is quite noticeable; and, since it is present even when the creep is not continuous, it constitutes a form of time-strain which has an importance quite apart from the question of failure.

We now see that the total extension at any time h may be expressed by

$$c \cdot u = \frac{h}{mh+n} + e^{r \cdot h} - 1 \quad - \quad - \quad - \quad (7)$$

for constant-stress and temperature conditions. The curve for u as so expressed is of the type indicated by the sketch, Fig. 13, which is somewhat similar to one presented by Mr. Tapsell, in the discussion on Prof. Lea's paper, as the typical curve of creep.

For the rate of creep, we obtain from (7)

$$c \cdot \frac{du}{dh} = \frac{n}{(mh+n)^2} + r \cdot e^{r \cdot h} \quad - \quad - \quad - \quad (8)$$

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and it is clear that the first term is diminishing while the second is increasing. Consequently there may be a period of time during which the rate of creep may seem practically steady. The actual range of steadiness will depend on the relations between the coefficients; but this characteristic of (8) would serve to cover the experimentally observed fact—used both by Chevenard and Lea—that after a time the specimen settles down to a steady rate of extension.

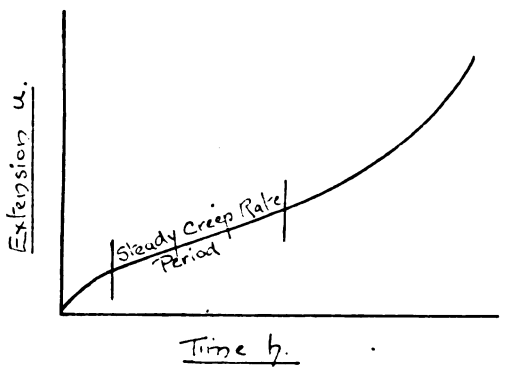

Fig. 13.—Typical Creep Curve.

While dealing with the subject of extension, it remains to show that the Chevenard type of curve (see Fig. 3) is inherent in the forms already deduced. The problem here is to determine $\frac{du}{dh}$ from equation (8) for a given value of h—say h_1—with r varied to suit different temperatures. Thus, in full, we get

$$c \cdot \frac{du}{dh} = \frac{n}{(mh+n)^2} + \frac{\log_e(cr+1)}{H} \cdot e^{\frac{h_1}{H}\log_e(cr+1)} \qquad (9)$$

and taking $T_0 = 1{,}290$ degrees F., determining H from (2) with $a = 0{\cdot}0044$ and $b = 0{\cdot}08$, and assuming $h_1 = 2{\cdot}5$ hours, the curve in Fig. 14 is obtained.

The various coefficients are merely guessed, yet the resulting curve is distinctly of Chevenard's type. The main point of

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difference lies in the fact that the true creep limit temperature is much further inside the curve than would be suggested by inspection of the experimental curves of Fig. 3. This shows the weakness of the experimental method, in that, while it suggests a limit, it does not properly guide the extrapolation process necessary to define it.

Chevenard's curves are obviously of an exponential type, but they are now seen to follow from the general discussion

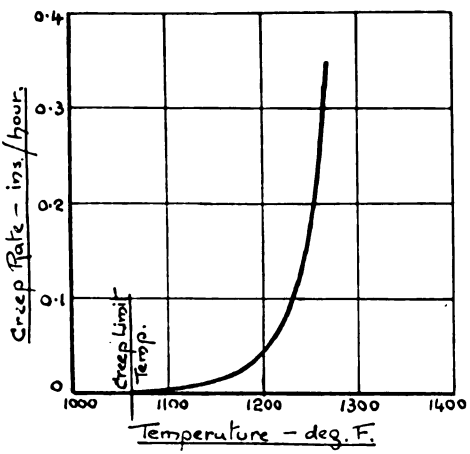

Fig. 14.—Creep Rate Curve by Equation (9).

of Dickenson's data. Since Lea's main results are similar in type to Chevenard's, we must conclude that all the main experiments in which extension has been measured, support the assumption of an exponential law of creep such as has been considered in this section.

The Creep Limit Curve. It has been shown that, for constant stress S_0, the basis test defines T_0 and the long-duration tests lead to the determination of a coefficient a, which by its reciprocal gives the temperature range of the creep field at S_0. Consequently we require the variation of a with S_0 to define the inner boundary of the creep field, the outer

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boundary being readily mapped out from the normal period tests.

The main guide here is the curve type, shown in Fig. 6, expressing Lea's limiting values. Similar indications are given by Brown's tests, Fig. 8. Generally, it is seen that the range $\frac{1}{a}$ narrows as S_o increases, and apparently tends to become zero over the low-temperature range when the full strength is maintained. There are several ways of expressing these facts. The data are much too indefinite and incomplete to determine which is the most correct, but the following is suggested as a fairly sound representation of the facts as they stand.

Instead of merely taking S_o as the variable on which a depends, we may take $\frac{S_o}{T_o}$, and so obtain a quantity which is increasing very rapidly in the lower temperature regions. Then a might be written as a function of this new variable, say

$$a = B\left(\frac{S_o}{T_o}\right)^{\beta} \quad - \quad - \quad - \quad - \quad (10)$$

which makes the creep temperature range diminish rapidly at the lower temperatures. Further, since this range is set off along a line of constant stress, it follows that the points on the creep limit curve given by (10) fall very nearly on the normal strength line, where the line is flat, as in the low temperature field.

Actually, for many cases, a simple linear function of $\frac{S_o}{T_o}$ may be taken, this being one of the advantages of employing $\frac{S_o}{T_o}$ as the variable. For example, consider the smooth S_o, T_o curve drawn in Fig. 15 as a typical normal strength curve. Then the two inner curves marked respectively I and II are obtained by using

$$\text{I.} \quad a = 0{\cdot}002 + 0{\cdot}065\frac{S_o}{T_o}.$$

$$\text{II.} \quad a = 0{\cdot}00225 + 0{\cdot}01\frac{S_o}{T_o}.$$

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It follows that it is possible to obtain a creep limit curve of a smooth order agreeing with the general type of Fig. 6 by means of an equation of the simple form—

$$a = A + B\frac{S_o}{T_o} \quad - \quad - \quad - \quad - \quad (11)$$

Although this function is continuous, it gives a practical discontinuity at some moderate temperature by reason of the flatness of the normal curve.

The method suggested for dealing with the limit curve meets the experimental facts quite reasonably. In the lower temperature field, however, these are really quite vague, being confined to the single observation that the full stress may be carried. Now a strict interpretation of the form herein imposed on the limit curve would be that, even at low temperatures, there is a temperature range of creep. Since the full strength is maintained, it follows that the time effect could only show on temperature considerations. It would appear irrational thus to interpret a suggested and empirical curve form, but actually the form has been arranged to introduce some such feature, and the evidence in favour thereof appears in the next section.

The Progressive Temperature Method. Consider a case in which the temperature of a specimen at constant stress is increased in regular steps at time intervals δh. Let the temperature commence from the creep limit value T_c, and increase by equal increments of $q \,.\, \delta h$. Then q is the rate of heating. Examination of equation (3) for extension will show that in the successive intervals 1, 2, 3 — — — n, we have

$$\log_e(cu_1 + 1) = r_1 . \delta h.$$
$$\log_e(cu_2 + 1) = r_2 . \delta h + \log_e(cu_1 + 1)$$
$$\text{— — — — — —}$$
$$\log_e(cu_n + 1) = r_n . \delta h + \log_e(cu_{n-1} + 1)$$
$$= \delta h(r_1 + r_2 + \text{- - — — } r_n)$$

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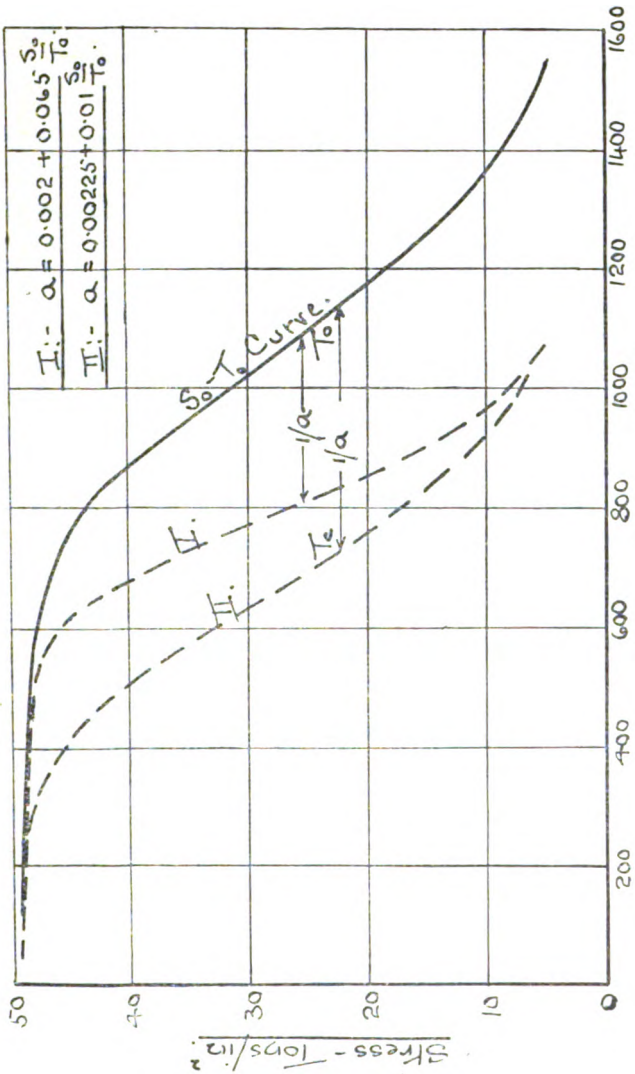

Fig. 15.—The Creep Limit Curve Form.

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If the specimen breaks at the end of the n^{th} interval, and we take $\bar{u}$ as the extension at failure, then

$$\log_e(cu_n+1)=\log_e(c\bar{u}+1)=\delta h.\sum_1^n r.$$

And since

$$r=\frac{\log_e(c\bar{u}+1)}{H},$$

it follows that

$$\delta h\sum_1^n\left(\frac{1}{H}\right)=1 \quad - \quad - \quad - \quad - \quad (12)$$

Now by (2) we have

$$\frac{1}{H}=\frac{1-at}{bt}$$

if we neglect k, which is of no great importance in the present issue. At any temperature T, $t=T_o-T$; and at the creep limit, $t_c=T_o-T_c$. If, then, failure is at temperature T_n, we have $t_n=T_o-T_n$, while the temperature range passed through from the creep limit to the breaking temperature is

$$T_n-T_c=t_c-t_n,$$

and the number of steps in the range is

$$n=\frac{t_c-t_n}{q\,.\,\delta h} \quad - \quad - \quad - \quad - \quad (13)$$

If we take the average value for $\frac{1}{H}$ as given by

$$\left(\frac{1}{H}\right)_a=\frac{1}{t_c-t_n}\int_{t_n}^{t_c}\frac{1-at}{bt}\,.\,dt$$

$$=\frac{1}{b(t_c-t_n)}\left\{\log_e\left(\frac{t_c}{t_n}\right)-a(t_c-t_n)\right\}, \quad - \quad (14)$$

then (12) becomes

$$n\,.\left(\frac{1}{H}\right)_a.\,\delta h=1,$$

so giving, by means of (13) and (14),

$$\log_e\left(\frac{t_c}{t_n}\right)-a(t_c-t_n)=b\,.\,q \quad - \quad - \quad (15)$$

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which expresses the breaking temperature in terms of the heating rate. Differentiating, and noting that $dt_n = -d\mathrm{T}_n$, we get

$$\frac{d\mathrm{T}_n}{dq} = \frac{bt_n}{1-at_n} \quad - \quad - \quad - \quad - \quad (16)$$

This equation states that at constant stress, within a creep range, the breaking temperature increases with the rate of heating, the rate of increase being equal to the duration of the specimen at the temperature at which it breaks.

Reference to Ingall's work (see Fig. 9) will show that the general effect disclosed by (16) is in keeping with the only experimental investigation on the influence of the rate of heating. Actually, Ingall expresses his result in the form

log. rate of heating = constant × breaking temperature.

but he suggests that it is possible the relationship between heating rate and breaking temperature is hyperbolic, although the data are insufficient to determine this. We now see that the relation is as in (15), and that the hyperbolic law applies to the rate of change of breaking temperature. The extension of our scheme to this particular case shows it to be competent to cover, in a general fashion, the available experimental facts.

As discussed by the investigator, the method was supposed to indicate what amounted to a creep limit, but it follows from this development that the approach of any breaking temperature to a true creep limit for the corresponding stress will depend on the heating rate.

Thus, if $t_n = w \,.\, t_c$, then from (15)

$$q = \frac{1}{b}\left\{\log_e \,.\, \frac{1}{w} - 1 + w\right\},$$

and for any reasonable value of w (·8 or ·9 say) the value of q would be extremely low. Consequently, for the heating rates that have been used—both by Ingall and Dickenson—the

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breaking temperatures are really much closer to the quick break value than to the creep limit figure.

A further point of considerable interest arises out of the discussion in this section. If, in the creep field, a decrease in the rate of heating lowers the breaking temperature, it should follow, conversely, that conditions under which the breaking temperature is so affected by heating rate must be in the creep field. Now Fig. 9, showing Ingall's results for copper, demonstrate that such conditions appear right down to quite low temperatures, and the same fact appears from all the materials investigated in this manner. Does it apply to steels? If so, we have at once a general argument which rationalises the special feature of the creep limit curve referred to in the last section. If, at low temperatures, a change in the rate of heating alters the breaking temperature, there must be a creep temperature range, even though the strength may be fully maintained. The point is perhaps of no serious practical importance, but it has a fundamental value, and would seem to mark an aspect of this subject in which the Ingall method of varied heating rate has a special merit and application. In any case, the final argument of this section must be taken as the justification for the particular form suggested for the creep limit curve in the preceding section.

The Progressive Stress Method. To complete the analysis of the experimental features, the method employed by Brown may now be considered. The mode of examination necessary here is somewhat similar to that of the last section, but, owing to the fact that the general scheme of analysis has been based on temperature ranges, the treatment of the progressive stress condition is not quite so direct as that for the temperature steps. With a little simplification it can be made reasonably concise, and provides sufficiently clear ideas of the matter.

In this case the temperature is constant, and the stress S increases at a rate Q, say, in time steps, δh, such that $Q \cdot \delta h = \delta S$. We consider the effects from the time of passing through the

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value S_c, the creep limit condition, until the failing stress S_n is reached. Let

$$S - S_c = s, \text{ and } S_n - S_c = s_n,$$

and assume that the essential a and b values, by which the duration is defined, remain constant within the range s_n. This assumption is quite reasonable, since, if the method is to have any value as a mode of search for the limiting conditions, s_n cannot be great.

By the procedure of the previous section we arrive at (12), but $\frac{1}{H}$ has now to be expressed in terms of stress instead of temperature. We have

$$\frac{1}{H} = \frac{1 - at}{bt}$$

but we may put

$$t = t_c - \frac{dT_c}{dS_c}(S - S_c) = t_c - \rho \cdot s \quad - \quad - \quad (17)$$

the value of ρ being determinate from the S_c, T_c curve, over the range s. Hence, for an average value of $\frac{1}{H}$, we obtain

$$\left(\frac{1}{H}\right) = \frac{1}{b \cdot s_n} \int_0^{s_n} \left(\frac{1}{t_c - \rho s} - a\right) ds$$

$$= \frac{1}{b \cdot \rho \cdot s_n} \log_e \left(\frac{t_c}{t_c - \rho s_n}\right) - \frac{a}{b} \quad \cdot \quad \cdot \quad (18)$$

Again, the number of steps is

$$n = \frac{s_n}{Q \cdot \delta h} \quad - \quad - \quad - \quad - \quad (19)$$

and hence, from (12) by using (18) and (19), we get

$$\frac{1}{\rho} \log_e \left(\frac{t_c}{t_c - \rho s_n}\right) - a \cdot s_n = b \cdot Q \quad - \quad \cdot \quad (20)$$

Equation (20 expresses the breaking stress in terms of the

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rate of loading and certain coefficients. If s_n is now replaced by $S_n - S_c$, and S_n is entered as $v \cdot S_c$, (20) becomes

$$\frac{1}{\rho} \log_e \left(\frac{1}{1 - a \cdot \rho \cdot S_c(v-1)} \right) - a \cdot S_c(v-1) = bQ \quad - \quad (21)$$

from which, if the various coefficients are known, or can be reasonably assumed, it becomes possible to determine the probable discrepancy between the breaking stress, as determined, and the true creep limit. It is obvious that there must be some difference, and this method of experiment can only be considered complete when that difference is reasonably defined. Equation (21) performs this duty if the simplifications in the analysis are permitted and exponential creep is correct. The method has only been used by Brown on non-ferrous metals, and the order of the creep effects on these has not been determined, but the assumption seems reasonable.

As an example, (21) may be applied to the monel metal data of Fig. 8. For any assumed S_c value, a and ρ can be roughly determined from the graph; b, however, is unknown. Taking $b = 10a$, it is found that, at a stress of 30 tons per square inch, and a loading rate of 1 ton per square inch per day, the value on Brown's curve is about 9 per cent. high; while at 15 tons per square inch it would appear to be about 15 per cent. high. These values indicate that the light dotted line sketched underneath Brown's curve in Fig. 8 would be an approximation to the true creep limit curve. While the b value will affect the conclusions to some extent, it may be remarked that the general laws of creep that have been established in our main discussion are of such an order that it will really be difficult to reduce the discrepancy much below 10 per cent. without a very low rate of loading. Also, a fairly rapid loading rate will still give an approximation within 20 per cent. In all, Brown's suggested rate of 1 ton per square inch per day promises to be quite serviceable, although it is not equally accurate at all points in the field.

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Conclusions.

The main purpose of the paper has been effected by the analysis that has been submitted, whereby the various lines of experimental data are found to be very reasonably in keeping with the two leading assumptions, namely, a hyperbolic law of duration and an exponential law of creep. It is perhaps desirable to remark briefly on how the findings of the analysis may influence experimental procedure, and how the subject must influence design.

Experimental work in such a line will always have a double aspect. On the one hand, it will be concerned with the physical mechanism of creep; on the other, it will have the duty of providing the essential information for the guidance of design. The former is unlikely to be greatly influenced by such processes as have been investigated, but must recognise and ultimately explain the laws deduced from experimental facts. The latter, however, must take cognisance of some such principles if the necessary information is to be established with sufficient completeness.

The scheme has been largely based on the short time test. This becomes the fundamental experimental procedure in the exploration of the qualities of the material, and the duration effects are to be related thereto. Very rapid loading must be avoided in the basis test, but anything between, say, five minutes and one hour would appear permissible. With that latitude it should be possible to determine the S_o, T_o curve for a given material with little more effort than is commonly expended on the usual quick-break high-temperature investigation.

Since equation (1) shows that

$$\frac{H-k}{T_o-T}=aH+b \qquad - \quad - \quad - \quad (22)$$

the duration effects at any one stress are determinate by a minimum of two tests fixing the straight line so expressed. If

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this form of the duration law is genuine, then two quite short tests should be sufficient to determine the slope of the line Then the limiting creep temperature T_c, for the stress used is determined from

$$T_o - T_c = \frac{1}{a} \quad - \quad - \quad - \quad - \quad (23)$$

Even if the line is not quite straight it can only be a very flat curve, and the slope from two tests is still a fair approximation. The whole point in the procedure is that the essential limiting condition—infinite in time—is derived from a few tests of relatively short duration. The analysis of the experimental work has, therefore, provided us with a scheme of search alternative to those that have been adopted by the different investigators.

If equations (10) or (11) should ultimately prove sufficient for the expression of the creep limit curve, then two investigations of the kind described in the last paragraph are the minimum for its determination. Thus, with two a values—for two widely different stresses—we have either

$$a = B\left(\frac{S_o}{T_o}\right)^{\beta} \quad - \quad - \quad - \quad - \quad (24)$$

or

$$a = A + B \cdot \frac{S_o}{T_o}$$

whichever is the more suitable. The necessary coefficients in (24) are then determinate, and the full creep limit curve is then obtainable from the basis S_o, T_o curve. The question of a creep temperature range at low temperatures is of less practical importance, but the forms given in (24) are competent to meet this condition if required.

There is no indication from experiment of how the b value in (22) varies with stress, but it is unimportant from the creep limit point of view. It could probably be expressed after the manner of (24).

The scheme of investigation so outlined is probably the

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irreducible minimum for the determination of a creep line. More would probably be done in any particular investigation. It is noticeable, however, that the method does not necessarily entail observation of the extension. This is a distinct simplification, if creep limits alone are required; but if a knowledge of the extension is necessary, it could probably be most conveniently examined during the basis test work. It could then be connected to the long-duration conditions by means of equation (5).

Alternative to the above method for the direct establishment of the creep limit curve, the progressive stress method could be used, if it were permissible to correct the values obtained by means of equation (21). This experimental process in itself, however, is unable to supply the a and b values—or similar information—necessary for the use of (21), so that the procedure is, on the whole, less definite. It has, however, the advantage of not requiring the extension measurements that always make any process involving a search for zero creep, or the extrapolation of observed creep rates, a matter of considerable labour.

It must be understood that this brief discussion on procedure is for the purpose of indicating the most rapid methods of deriving creep limit values of such an order as are required in design. It does not seek to deprecate the more laborious and direct methods of search which have been, and are being, followed. These will always have a fundamental value and an essential application, but we may be permitted the guidance they afford towards much quicker methods of quite sufficient comprehensiveness for all practical purposes.

One point regarding experimental matters must be emphasised. It is clear from all aspects of the subject that the temperature is of vital importance, and proper methods of measurement and control are essential. A recent publication*

* "Accuracy in High Temperature Testing of Materials." Spring and Kanter. Power, Sept. 1, 1925.

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has shown that the methods of furnace winding and of temperature measurement may have quite considerable influences on the results obtained in normal high-temperature work. The curve of tensile strength may easily be misplaced. The same matters are of still greater moment in creep investigations, where the life of a specimen may be quite drastically affected by small changes in temperature or by temperature variations throughout the length. It is necessary to realise that in the creep field the temperature influence is much more profound than that due to stress.

The designer proposing to employ materials in the high-temperature field must also appreciate the significance of the temperature influence. He must realise that ordinary factors of safety, on a stress basis, have degenerated into mere margins of safety in time and temperature. Thus, if it is proposed to use a given material at stress S and temperature T, when for this stress the basis test temperature is T_o, then the time to failure is given by

$$H = \frac{b(T_o - T) + k}{1 - (T_o - T)\left(A + B \cdot \frac{S}{T_o}\right)} \quad \cdot \quad \cdot \quad \cdot \quad (25)$$

If this is positive, only a margin of time is really available; and if S or T should be subject to any increase, that margin is seriously reduced.

If (25) is negative, then the material is safe in time, but a temperature margin appears. This is

$$(T_c - T) = (T_o - T) - \frac{1}{A + B \cdot \frac{S}{T_o}} \quad \cdot \quad \cdot \quad (26)$$

and if the temperature is liable to a known fluctuation the margin is correspondingly reduced.

A stress factor of safety may be considered in the usual way, using the creep limit curve for ultimate strengths, but

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generally it is quite unimportant relative to the temperature margin, which will nearly always provide the true criterion of safety.

These time and temperature margins are the all important practical issues of the subject of continuous creep. Unfortunately they are not the only matters that must be appreciated by the designer. The possible deformation of the material under working conditions introduces a more subtle point into design involving materials at high temperatures. Even if the creep field, as studied herein, is definitely evaded, the experimental work which has been discussed shows the possibility of initial time extension that must create serious difficulties in practice. This special aspect of creep investigation promises to be of considerable importance. It is much too vague at the moment, even experimentally, and it is doubtful whether its true significance has been rightly assessed, unless it is this effect that is covered by Fahrenwald's secondary unstable field. The designer may be successfully shepherded off the creep field proper, but if, feeling safe, he is thereby induced to work in a range involving initial non-continuous creep that is real and insidious, he may have to face ultimate stresses that are excessive, because of deformations that were unforeseen. While specifically concerned with the limiting conditions for continuous creep, we may be permitted this brief warning regarding the non-continuous variety that, so far as design is concerned, is dangerous only in a slightly less degree.

I desire to thank Mr. J. S. Brown, M.B.E., A.R.T.C., who has, throughout the course of an experimental investigation extending over several years, freely related his experiences with various metals on long duration tests covering a wide variety of conditions. The advantages derived therefrom have been considerable, and are gratefully acknowledged.

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Discussion.

Prof. A. L. Mellanby, D.Sc. (Member): It would scarcely be a compliment to the lecturer to enter upon any serious discussion of such a paper in the short time that is left at our disposal. I am, however, pleased to have the opportunity of congratulating both Prof. Kerr and the Institution upon the paper we have had this evening. The paper divides itself readily into two main sections. The first portion gives a detailed account of practically all the work that has been published upon high-temperature testing of materials. Up to now those interested in this particular branch of materials testing have had to search through the engineering journals or the proceedings of the various technical societies to find the information they needed. The advantages that this paper now gives us, of having the details of such work in a form so convenient for reference, will be much appreciated by designers and those interested in high-temperature high-pressure plants. It is also of great value to know the procedure adopted by the different investigators, and this is a part of the work to which Prof. Kerr has given much attention. The second part of the paper will also be of great value to those interested in such researches. It represents the first real attempt to put the different experimental results on a common basis, and indicates, at the end of a remarkably ingenious piece of analytical work, a mode of experimenting which has every promise of giving results suitable for practice with the minimum expenditure of time.

This subject of tensile strength at high temperatures is one in which I have been interested for a long time, although the material used in my own experiments was cast-iron, to which some of Prof. Kerr's conclusions probably do not apply. There is one point which has to be considered in dealing with cast-iron, and that is the change of composition which results from a period of heating to even moderately high tempera-

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tures. This is a feature upon which some valuable work has been done Mr. J. W. Donaldson* in the laboratories of Messrs. Scotts' Shipbuilding and Engineering Co., Greenock, where he has studied the effects of annealing cast-iron specimens for periods of 200 hours at different temperatures. After these periods of heating, the bars were subjected to high-temperature testing in the usual manner, that is to say, the specimens were taken to the testing machine, placed in an electric furnace, and raised to any desired temperature. After being maintained at that temperature for about half-an-hour, the load was applied until fracture took place. By comparing the results so obtained with those from bars which had not received the previous annealing treatment, Mr. Donaldson is able to show that the changes produced by the annealing had caused quite an appreciable loss of strength at all temperatures.

Some years ago, when marine engineers were commencing to take a real interest in Diesel engines, I was asked by the British Marine Oil Engine Manufacturers' Association to undertake some experimental work upon the properties of cast-iron at elevated temperatures. By the kindness of the Association, I have been permitted to show a diagram illustrating how the strength of cast-iron changes with increasing temperature, Fig. 16. In the early experiments the tests were carried out in the usual way; the bars were heated in an electric furnace attached to the testing machine to some desired temperature, kept at that temperature for half-an-hour, and then loaded until fracture took place. An interesting feature of these experiments, which was, I think, here indicated for the first time, was the fact that cast-iron had a minimum strength somewhere in the neighbourhood of 400 degrees F. Various inconsistencies were noticed in the course of these tests, and it became apparent that the duration

* "Low-Temperature Heat Treatment of Special Cast-Irons." J. W. Donaldson, B.Sc. Inst. of British Foundrymen, Glasgow Conference, 1925.

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Prof. A. L. Mellanby, D.Sc.

of the heating period had a marked influence upon the results. The method of testing was then altered, and a special machine devised, in which it was possible to maintain the

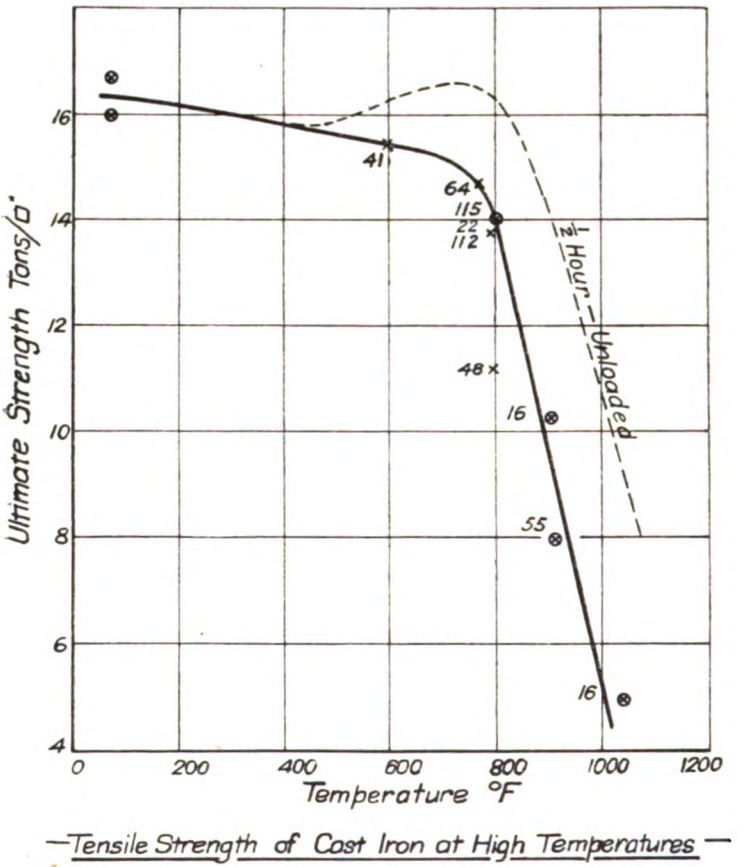

Fig. 16.

test pieces under load at any desired temperature for long periods. The results of one such set of experiments are given in Fig. 16, where the full line shows the strength as determined by keeping the specimen under load at the different

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temperatures for long periods. The dotted upper curve shows the results obtained with the half-hour tests, and a comparison of the two sets of results reveals how misleading these short time tests may be. The influence of duration of time upon the breaking strength is also shown in the following table, when the specimen was raised to 1,025 degrees F. and maintained for different periods at that temperature before being broken:—

	Breaking Strength. Tons per Square Inch.
Specimen raised to 1,025 degrees F. and immediately broken - - - -	13·5
Specimen kept at 1,025 degrees F. for half-an-hour and then broken - -	10·0
Specimen kept at 1,025 degrees F. for 15 hours and then broken - - -	4·0

Although the illustrations given scarcely fall under Prof. Kerr's heading of "Failure by Creep," yet it is felt they do offer some useful information, and may be considered worthy of inclusion in the discussion on the paper.

Mr. JOHN S. BROWN, M.B.E. (Member): The first part of this paper provides a review of the more recent developments in materials testing, and those who find it new are at least fortunate in having the essential matters picked out from the masses of experimental data, and put before them in a concise form. It is shown that the simple tensile test, as commonly used for the classification of materials, may give information which the engineering designer can only regard as totally erroneous, the fault being due to secondary influences, which only become evident when the test load is applied for a very extended period of time. While it may appear disconcerting to find that numerous groups of well-established figures have suddenly been discredited, through the substitution of much lower strength values, it should be noticed that it does not entail any

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Mr. John S. Brown, M.B.E.
direct reflection on current engineering practice, as, in general, the defect in the data is already covered in the crystallised experience which passes under the name of "factor of safety." But, naturally, it will be discreet to readjust that factor in terms of the new strength values. Outside the field of current practice, where new developments impose novel conditions on the materials, it becomes of primary importance to study the new strength values. Indeed, the new tests provide immediate limits to the applications of the whole range of known materials, at temperatures little different from those now in use in modern power plants. In this latter connection, it is to be noticed that the subject under discussion is the final failure of the material by mechanical fracture, which is now shown to be approached through a gradual deterioration, or creep, while under load over an extended period. But under slightly less severe conditions the distortion may commence as before, and then, through the influence of strain hardening, this action may eventually cease, so giving stability, but with a deformation much in excess of the legitimate elastic extension. There are few engineering applications where such deformation can be accepted with safety, and a warning to this effect is conveyed at the end of the paper; so that in the field of engineering development a further margin may have to be allowed below the strength shown by the new tests.

The title and trend of the paper suggest that the effects brought out by the long period tests may be appropriately considered as a distortion, or creep action: but, to me, it is not at all certain that this generalisation is justified; as in the case of cast-iron, and also for some non-ferrous alloys which are commonly understood to be ductile, the fracture can occur without any evidence of a change in dimensions. The action is then a time effect strictly, and in some instances may arise from a chemical redistribution of the constituents. But for the larger group of materials, in which the steels are included,

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the failure is approached through a viscous flow or creep; and here the exponential relationship developed by Prof. Kerr will be of great value in defining the boundary of the dangerous field.

In the general case, we may have to derive the limiting safe stress without assistance from the extensometer; and the form of the test then reduces to an extended observation of the behaviour of the specimen while under selected conditions of load and temperature. Here a limiting value is only given when the specimen fails, and its interest varies directly with the duration of the test, the resulting value being the appropriate working stress for a "useful life" corresponding to the period under test. Prof. Kerr shows how such a test may be replaced by a series of tests of relatively short duration, which are then to be extended on the assumption of a relationship of hyperbolic form. This relationship is certainly more rational than the logarithmic system used elsewhere, and is not only supported by the data presented in Fig. 11, but also by the general form of the data provided in the "history" lines of my own investigations. The suggested procedure, therefore, provides a concrete and straightforward basis for a systematic investigation, but its ultimate value depends on the hyperbolic relationship being applicable to the material under test. To check this, it will be necessary to make more extensive tests at one or more selected points on the curve. It is quite certain that occasional exceptions will be found, as in my tests on a 30-ton brass the conditions at 670 degrees F. gave failures in a uniform time of two hours, with the widely varying stress values of 10, 7½, and 4 tons per square inch. In this circumstance my closing note must again draw a warning from the misleading results given by the artificially rapid procedure of the old form of test, and would suggest that any alternative "dodge" for shortening the test from a really extended investigation must be very closely examined for secondary errors.

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Mr. Donald MacNicoll.

Mr. DONALD MACNICOLL (Member): Prof. Kerr's paper is of general interest to engineers, particularly to those engaged on the design of high-pressure steam plants. It is of particular interest to me, because on behalf of my firm the late Prof. Longbottom conducted time-temperature tests on certain non-ferrous metals in the years 1911 and 1913 at the Royal Technical College.

The 1913 tests were perhaps not, properly speaking, time-temperature tests. They consisted of soaking specimens in superheated steam for from three to four months, and then testing at the average superheat temperature against specimens untreated but raised to the same average temperature. The material was known as crotorite bronze. The 1911 tests, however, consisted of testing, first at normal temperature, then at various temperatures, but only soaking the material for a short time at any particular temperature. One of the temperature tests was then selected, and the temperature maintained on the specimen for 24 hours. Load was then applied until the specimen broke. Another specimen was soaked for one week at the same temperature, and then broken. This material was a phosphor bronze. Although the conditions of testing were different to those described by Prof. Kerr, inasmuch as that stress was not applied during the time period, yet the results were somewhat similar to those shown for monel metal in Fig. 8, although the initial tensile strength of the metal was not quite so high.

Prof. Longbottom was deeply interested in these experiments, and I gathered from his remarks at the time that there had been no prior temperature tests, at least in so far as a time element was concerned. He suggested to me the carrying out of further experiments, but I realised, however, that my firm had received the information required, and regretted that no further experiments need be conducted on their behalf. At the same time I believe Prof. Longbottom did carry out subsequent investigations, and I should like

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Mr. Donald MacNicoll.

to know if Prof. Kerr has any knowledge of these experiments, and if they had any bearing upon the present subject.

Since this paper was read a case occurred which suggested failure by creep, and although I anticipated much that Prof. Kerr states at the end of his paper about subtlety of design, it will be appreciated that I felt somewhat uneasy, as the pressure was 800 lbs. and the temperature 842 degrees F. However, I am glad to say that the slight trouble does not appear to be due to creep. On the other hand, I agree with Prof. Kerr that the question of creep will enter largely into design at high pressures and temperatures, and that a point will be reached where it may be necessary that, after a period of running, a plant must be shut down to recuperate. On marine work this period occurs almost automatically, while in power stations, plants are often in duplicate; but the whole question is one of economic balance.

Mr. C. R. H. Bonn (Associate Member): I think the most noticeable thing about Prof. Kerr's paper, apart from his work and the conclusions he arrives at, is his description of the development of this particular research, and what the different researchers engaged in it have accomplished. Remembering the dry-as-dust text-books used in old college days, containing, at most, a few scanty references to notable men of science, I feel sure that if Prof. Kerr's text-books are written in the same vein as his paper they will be much more interesting, and certainly more inspiring, than the old ones.

While giving the researchers due credit, Prof. Kerr, in reviewing their work, sums it up on page 352 by saying: "This shows the weakness of the experimental method, in that, while it suggests a limit, it does not properly guide the extrapolation process necessary to define it," and justifies this by providing a brilliant mathematical analysis of the facts. It is a pity that mathematical analysis of facts is so often

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Mr. C. R. H. Bonn.
neglected, because a great deal of research work is of little or no use at all unless extrapolated in this way. Especially is this the case where there are several factors and no means of observing them separately. In this case there are three factors entering into the extension, namely, stress, temperature, and time, and the great duration of the tests which would be necessary properly to estimate the time limit makes such tests impractical. Prof Kerr seems to prove that by taking short duration tests of the rates of creep at given temperatures and stresses he can, mathematically, find the temperatures for zero creep at a given stress, or the stress for zero creep at a given temperature. By means of the formulæ he has evolved, together with constants found from the plotted curves, he provides information in a form that engineers engaged on temperature work may readily apply. A great deal apparently remains to be done in investigating the effect of temperature on the different kinds of stress, and, in view of the increasing importance of such investigations, it is to be hoped that there will be no delay in carrying them out.

Prof. Kerr states that in the subject of materials testing "The ultimate aim is that rigorous and comprehensive theoretical analysis which illuminates and displaces the compilations of experimental observation in the process of explaining them. In the subject of materials, that general treatment is almost beyond hope." While I appreciate the importance of Prof. Kerr's work, and realise that a comprehensive theoretical analysis is not yet in sight, I should be sorry to think that it was almost beyond hope. As I stated in the discussion on Dr. Brown's paper last year, I think little real progress can be made until such an analysis is attempted, and it is time the purely engineering aspect was separated from the scientific. I thoroughly agree with Prof. Kerr when he says, "In such a study as this it is much more important to embody the main features of a set of results than to express each curve with meticulous accuracy." This almost appears

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to me as a well-merited snub to a certain kind of intellectual snobbishness.

Prof Goudie, in his paper on "The Internal-Combustion Turbine," read last year, mentioned that the material found most useful for the blading of the Holzwarth turbine was an electrolytic iron, and as a curve for this material appeared in one of Prof. Kerr's slides it would be interesting if he would include it in his reply. Prof. Kerr's paper reveals the fact that there has been a tremendous amount of investigation, of which most of us were aware, into these facts. I think it is a very bad thing for industry that such investigations should be hidden; in fact, it is to publish and bring forward information such as this that our Institution exists. I should like to see a limit put to the time during which researches carried out for private firms and individuals may be kept secret, say, not to exceed that required to secure the patent rights. Secrecy is dangerous to industry from the economic point of view. An example of this is the exploitation by the Perlite Company of a new process for casting iron under patents originating in Germany. I think there is little doubt that British firms have practised at one time or another many, if not most, of the methods covered by these patents. Now these people, I take it, are out to exploit the cast-iron trade, and it will be very difficult to contest their rights because the methods pursued are practised secretly and are never published. This points out the danger of not disclosing scientific facts, quite apart from the view that the publication of scientific investigations and researches leads to general progress, and does a great deal of good, while it can do little, if any, harm.

Mr. ALEXANDER S. CLARK, B.Sc: In his conclusions Prof. Kerr emphasises the importance of temperature measurement, and refers to the work carried out by Messrs. Spring and Kanter, which was published in "Power." I agree that

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Mr. Alexander S. Clark, B.Sc.
accurate temperature measurements should be made, and when measuring test-piece temperatures I use a copper-constantin thermo-junction, which is remade for every new test. This junction is tied to the test-piece, and shielded from radiation and the surrounding hot atmosphere by strapping the junction with asbestos cord. In their investigations Messrs. Spring and Kanter use a full-wound furnace, and at a temperature of 500 degrees F. they obtain a difference of 85 degrees F. at the surface of the test-piece between the centre and the top of the test length, the distance between these two points being one inch; while at the centre between the surface and the axis of the test-piece they record a difference of 130 degrees F., this distance being one-quarter of an inch. These differences represent approximate temperature gradients of 85 and 520 degrees F. per inch respectively.

In my investigations at the Royal Technical College, at a temperature of 780 degrees F. measured at the centre of the test length, I have found that one-half inch above the centre the temperature is lower by 28 degrees F., which gives a gradient of 56 degrees F. per inch, and this, considering the difference of test temperatures, compares favourably with the American results.

I consider the temperature gradient of 520 degrees F. per inch excessive, and submit as an explanation that the method adopted by Messrs. Spring and Kanter of measuring surface temperature is faulty. In what they publish they give no account of how the thermo-couple was fixed to the test-piece, nor how it was shielded from the furnace wall radiation and from contact with the hot atmosphere. That they did not take adequate precautions against this radiation is a feasible explanation of the excessive temperature gradient from the surface to the interior of the bar. It may be taken that the measurement of the internal temperature is free from such inaccuracies. Such figures as are available for gap winding indicate that, in this case also, shielding was inadequate.

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Regarding the displacement of the strength curves, wherein a full-wound furnace induces a higher stress value than a gap-wound furnace, it is noticed that by using the latter the stress-temperature curve is displaced about 100 degrees F. from the curve obtained when using full winding, that is, the breaking temperatures are lowered by 100 degrees F. In the tests described the specimen temperature is taken on the axis at the level of the top shoulder when using gap winding, and on the surface at the centre of the test-piece when using full winding. An examination of Messrs. Spring and Kanter's results indicates that, in the case of the bar heated in the full-wound furnace, the temperature recorded at the outside centre is in the region of 100 degrees F. in excess of the actual temperature of the bar. The poor protection of the thermo-junction might easily explain this difference, and also the displacement of the stress-temperature curve. The gap-wound curve is correct, and with accurate temperature measurements the full-wound curve would be coincident.

A test-piece in a full-wound furnace has a hot centre, with an almost uniform temperature over a short part of the test length. In the vertical furnace used at the Royal Technical College, this hot centre is located at a little above the geometric centre of the test-piece. Since all high-temperature stress work shows that a material is weaker at high than at low temperatures, it will be readily acknowledged that the material will break at the hottest part when sufficiently stressed, and if the temperature is measured at this section an accurate record of the breaking stress and temperature will be obtained. Again, consider the determination of a creep limit for a uniform temperature along the test length. At some stress below this limit the creep ceases, and at the creep limit stress it persists till fracture occurs. If in some other determination the breaking section is hotter than the rest of the test length, then, as the case may be, the creep will still stop or persist at the breaking section. This uneven tempera-

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ture distribution will diminish the creep figure, but will in no way affect the stress value.

In an effort to observe extensions, an Ames clock gauge was fitted to the Brown machine to measure the displacement of the straining head. This displacement, although subject to variation of stress on the straining rods, gives a fair indication of the elongation of the test-piece. The increments of stretch are fairly regular from day to day; a large departure therefrom is regarded as indicating the creep limit. Using the data thus obtained, and the equation $a = A + B\frac{S}{T_o}$, and plotting the values a and $\frac{S}{T_o}$, a straight line is obtained from which the constants A and B may be determined. The complete equation gives a smooth creep limit curve.

Dr. R. M. Brown, B.Sc. (Member): Much work on "creep" has been done during the past few years, and it was extremely desirable that someone should survey the general position and give a concise resumé of the state of our present knowledge. In this work Prof. Kerr has succeeded admirably, and has presented an excellent paper.

One may, perhaps, be forgiven for assuming that the phenomenon of creep is a comparatively recent discovery, but this is not so. More than 35 years ago, Prof. Barr began to emphasise the importance of the time element in the testing of materials, even at normal temperatures. He showed that the rate of loading had considerable influence on the ultimate strength of a wire; the breaking load was reduced as the rate of loading was diminished. He also pointed out that any stoppage or interruption in the continuity of loading resulted in a gain of length of the wire due to creep under constant stress. His object was to show that ultimate strength was not a definite physical property of a material, but that it was a function of the conditions under which the material was tested.

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Some diagrams and test results were given in a paper read before the West of Scotland Iron and Steel Institute in 1910.

The test results then published showed that a mild steel wire, which had a tensile strength of 21 tons per square inch when loaded at the rate of 18·2 tons per square inch per minute, broke under a stress of 19 tons per square inch when loaded at a ratio of 0·015 ton per square inch per minute.* Curves were reproduced which had been published some 20 years previously showing similar effects. Tests were carried out at temperatures which ranged between 37 and 171 degrees F.

The work recently done on creep carries this earlier work to its logical conclusion by investigating the ultimate strength when the rate of loading becomes zero—that is, at constant load—and by continuing the work in the high-temperature region where the phenomena due to creep are very much more marked. The creep limit, or the minimum steady stress which will ultimately cause failure, is of the utmost importance to the engineer, but is only one aspect of a much wider question.

A high-grade engineering material should have the following properties:—

1. The modulus should be high, and the stress-strain curve reasonably straight. This ensures that strains shall be a minimum, and that departures from proportionality of stress to strain are not sufficient to preclude the use of a simple value for Young's modulus in making calculations. Many materials show very low values for the modulus at high temperatures. This consideration alone is quite sufficient to render them unsuitable for use under such conditions. Rapid reduction in the modulus is generally associated with a low creep limit, but the importance of the modulus should not be entirely overlooked.

* That is, the tensile strength was reduced by about 10 per cent. when the duration of the test was extended from a little over one minute to 22 hours.

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Dr. R. M. Brown, B.Sc.

2. The creep limit should be high.
3. The endurance range should be high.
4. The material should offer a high resistance to fracture under impact.

"High" is, of course, a relative term; the absolute value would depend on the nature of the material and on the purpose for which it is required. These conditions must be satisfied at any temperature to which the material is to be exposed.

The engineer bases his faith in a metal largely on the determination of the yield stress and ultimate strength. Many materials do not show any definite yield point, and ultimate strength is of no direct importance to the designer. It is of indirect importance only when it gives an approximate idea of the value of the creep limit and of the endurance range. Most engineering materials show a creep limit at normal temperatures only a little lower than the normal ultimate strength, and, for steels at any rate, the ultimate strength gives an approximate idea of the endurance range under reversed stresses.

Prof. Kerr quotes some authorities in support of the opinion that, at normal temperatures, there is no perceptible difference between the creep limit and the ultimate strength. Prof. Barr's paper gives curves which show quite a considerable difference, although his lowest curve is undoubtedly higher than the creep limit. Some experiments I made last year illustrate the same point. On page 332, Prof. Kerr points out that the "creep and halt" method of testing gives high values. In this connection it must be clearly understood that, as with human material, engineering materials can be "trained" to carry greater loads than they will sustain when in their normal condition, and that a course of physical training may be very beneficial. This is illustrated by the following figures obtained during the experiments referred to above. The material was mild steel conforming to specification 2.S.1, and was in the annealed condition. The normal tests were made using an extensometer

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up to stresses slightly beyond the yield stress. Loading was, therefore, slow to the yield point, with faster loading beyond this stress. No attempt was made to determine the exact value of the creep limit, but the figures are interesting as showing how the creep limit may be affected by different conditions of testing. They also illustrate the effects of a course of training on the strength of the material.

1. Normal test, 32·2 tons per square inch.
2. Loaded to 31 tons per square inch, broke in 9¾ hours.
3. Loaded to 25 tons per square inch and raised by 1 ton per square inch per day to 31 tons per square inch, broke at this load in 52 hours.
4. Tested under a fluctuating stress for 6×10^6 stress cycles, maximum stress + 28·88 / minimum stress + 17·12 } range 11·76 tons per square inch. Then loaded to 28 tons per square inch and raised by 1 ton per square inch per day to 31 tons per square inch. After two days at this stress the load was raised to 32 tons per square inch, and the specimen fractured in four hours.

The figures indicate that the breaking load, even at normal temperatures, may be reduced by slow loading, and are in general agreement with Prof. Barr's results. The curve reproduced in Fig. 6 indicates that no rate of loading effects can be discerned below a temperature of about 500 degrees F. This is contrary to the results obtained by most experimenters. The creep limit of a mild steel in the annealed condition may reasonably be expected to occur from 1½ to 2 tons per square inch lower than the normal ultimate strength. A fluctuating load which does not break a specimen raises its ultimate strength, and, therefore, also its creep limit under steady stress. It is certainly possible, by varying the conditions of testing, to raise the creep limit to a value slightly higher than the normal ultimate strength of the material.

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Dr. R. M. Brown, B.Sc.

The researches to which Prof. Kerr refers deal only with creep under steady stress. The question of creep under fluctuating stresses must not be overlooked. This opens a very wide field to the investigator—a field which, as yet, is practically uncultivated. When a material fails under reversed stresses of comparatively low value but applied a large number of times, failure is said to be due to fatigue—a phenomenon for which no entirely satisfactory explanation has yet been offered. If a mean stress is applied to the material, the permissible stress range for an indefinite number of stress cycles is reduced, and if the mean stress be sufficiently high the normally recognised fatigue effects appear to diminish, while those recognisable as creep effects begin to be more apparent. Ultimately, if the mean stress be sufficiently high, creep is undoubtedly the predominating influence, although the effects are somewhat modified by the fluctuation of the stress.

The normal form of a reversals-stress range diagram is well known. The asymptote to this curve is assumed to give the maximum permissible range of stress which can be applied to the material for an indefinite number of cycles. As the mean stress is raised, there arrives a time when it becomes increasingly difficult to obtain such a diagram, since fracture either occurs under very few stress cycles or the test piece will be unbroken after a run of from 6 to 12 million cycles, a range which is usually assumed to indicate, very approximately, the endurance range for the material. Under such conditions of testing there is considerable creep in loading up, and if this creep reaches a critical value flow becomes more pronounced, and the specimen rapidly creeps to the point of fracture. If the critical point be not reached, a long run is generally ensured. The margin between a stress which will cause fracture within a few minutes and one which will fail to break the specimen after a run of 8 to 10 million cycles, may only be a fraction of one ton per square inch. The stress range

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under such conditions requires to be very carefully controlled to enable a successful test to be made.

In normal reversed stress tests made in the Haigh testing machine, there is practically no creep until a second or two before fracture takes place. A change in the note of the machine is heard, the ammeter shows an out of balance reading indicating that extension has taken place, and failure occurs in one or two seconds, usually before the machine can be reached or any adjustments made.

The following table gives some idea of the "brackets" obtained between broken and unbroken tests, and indicates the difficulty of drawing a range-reversals curve for high mean stresses. The material was annealed mild steel, for which results of creep tests have already been given:—

Mean Stress. Tons per sq. in.	Range of Stress. Tons per sq. in.	Maximum Stress. Tons per sq. in.	Cycles.	
0	26	± 13	$2{\cdot}32 \times 10^6$	Broken
	25	$\pm 12{\cdot}5$	$2{\cdot}41 \times 10^6$	Broken
	24·92	$\pm 12{\cdot}46$	$9{\cdot}276 \times 10^6$	Unbroken
+6	23·8	+17·9	$1{\cdot}824 \times 10^6$	Broken
	23·4	+17·7	6×10^6	Unbroken
+10	22·8	+21·4	$1{\cdot}688 \times 10^6$	Broken
	22·6	+21·3	$8{\cdot}75 \times 10^6$	Unbroken
+14	19·8	+23·9	$1{\cdot}748 \times 10^6$	Broken
	19·8	+23·9	$6{\cdot}044 \times 10^6$	Unbroken
	19·6	+23·8	$9{\cdot}232 \times 10^6$	Unbroken
+18	17·14	+26·57	40,000	Broken
	17	+26·5	30,000	Broken
	17	+26·5	$8{\cdot}84 \times 10^6$	Unbroken
	16·8	+26·4	$9{\cdot}03 \times 10^6$	Unbroken
+23	12	+29	52,000	Broken
	12	+29	40,000	Broken
	11·8	+28·9	6×10^6	Unbroken
	11·76	+28·88	6×10^6	Unbroken

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Dr. R. M. Brown, B.Sc.

Only a small selection of the test results have been quoted, but the results have been confirmed by further tests and by other tests on different materials. In some cases the margin

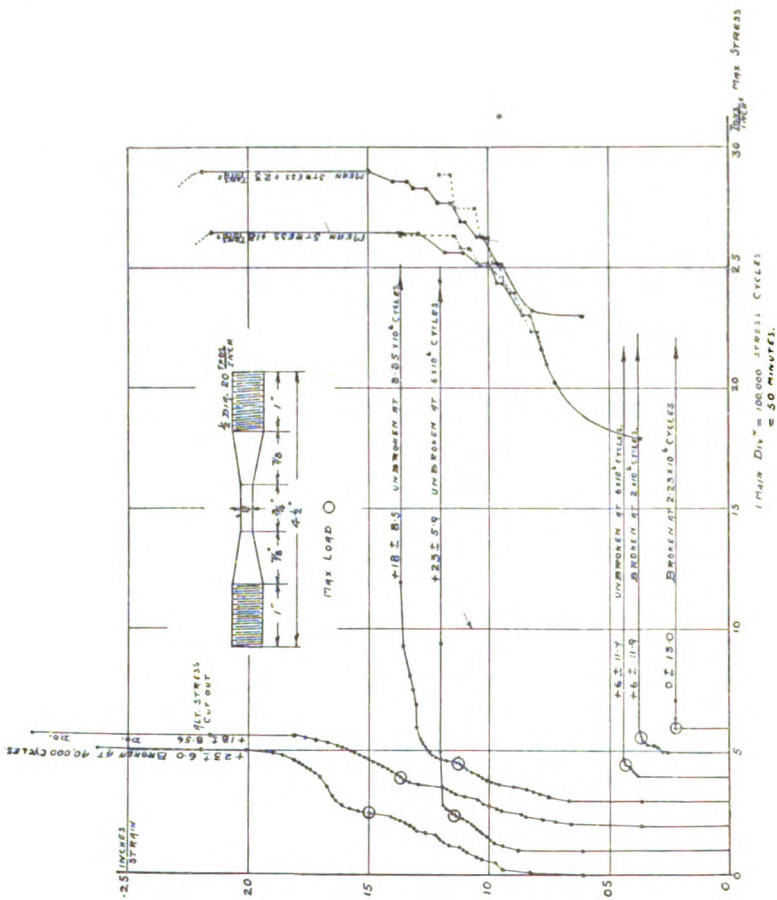
Max Load
Unbroken at 9·85 10⁶ cycles
Unbroken at 6 10⁶ cycles
Broken at 2·33 10⁶ cycles
Unbroken at 6 10⁶ cycles
Broken at 2 10⁶ cycles
Broken at 130
Mean Stress
Alt. Stress
Max. Stress
Tons/sq. inch
Main Div" = 100 000 stress cycles = 50 minutes.

Fig. 17.

between tests which fail in two minutes, that is, 4,000 cycles, and tests which are unbroken after 10 million cycles is only 0·2 ton per square inch, and the tests can be repeated with reasonable certainty.

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Typical creep diagrams are shown in Fig. 17, which also shows some corresponding stress-strain curves drawn for the maximum stress in the material. Fig. 18 shows loading

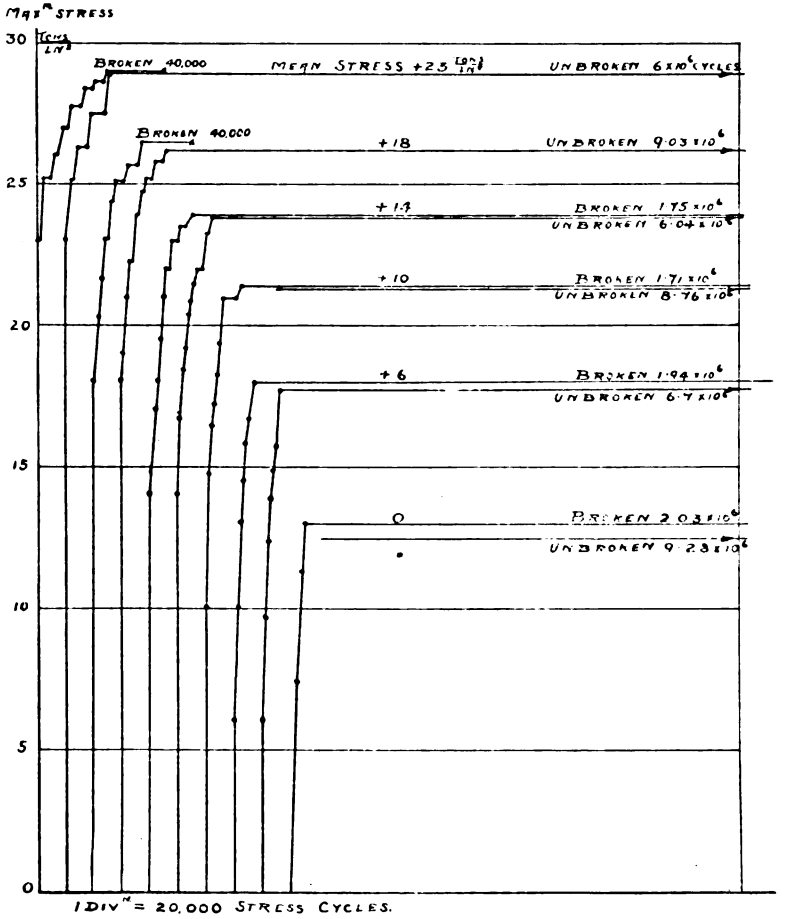

FIG. 18.

diagrams plotted on a time, or number of cycles, base, and illustrates again the difficulty of drawing a range-reversals diagram and estimating the asymptotes. The points at which

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full load was applied are indicated on the diagrams, and illustrate the growing effect of creep as the mean stress is raised. The unstable condition at high mean stresses is characteristic of creep phenomena, and is observable even under statical tests; the last fraction of a ton per square inch converts the creep from the non-continuous to the continuous condition.

The evidence goes to show that when a fluctuating stress is superimposed on a high tensile-stress, there is a new, and fairly definite, creep limit established for the material under such test conditions. This new creep limit depends on the mean stress and on the conditions of the test, and it defines the safe range of stress which may be applied under the given conditions. With a suitable course of training, this new creep limit may be actually higher than the normal statical ultimate strength, but, in general, it is lower. The figures already given indicate a maximum stress of 29 tons per square inch for the tests there recorded; this is, almost certainly, lower than the creep limit under statical loading. It seems to be probable that, if failure is due to creep, an estimate of the safe range, based on 12×10^6 cycles, is not sufficient to ensure complete safety, and the vexed question of determining the asymptote to the range-reversals curve may take on a new aspect as applied to fluctuating stresses superimposed on high mean stresses.

The mean stresses at which the critical condition supervenes are much higher than are met with under practical conditions, but experience with creep under statical stress has shown that what occurs at normal temperatures generally occurs in a greatly exaggerated measure at high temperatures, and it is extremely probable that creep will be found to be the predominating factor in failures under fluctuating stresses at comparatively low values of the mean stress in the high-temperature region.

The graphs shown give qualitative results only; the shape of the test specimen does not lend itself readily to exact

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quantitative results. The evidence goes to show that creep and fatigue are not entirely dissociated phenomena, and both must be considered in any complete investigation. When to the complexity indicated at normal temperatures is added the effects at temperatures which range from well below zero to the highest temperatures which exist in internal-combustion engines, and the effects of rapid variations in temperature such as are found in modern aircraft practice, the almost infinite ramifications of the subject in investigating the properties of even a single material, will be appreciated.

A paper, such as Prof. Kerr's, which presents in small compass the summary of our present knowledge, and gives a bird's-eye view of the position, is of inestimable value when planning a further line of attack. The paper will be greatly appreciated by all investigators in the subject of testing of materials.

Prof. B. P. Haigh, D.Sc.: Prof. Kerr's paper will be appreciated by those who may be called upon to carry out research, as well as by those who use or propose to use metals at temperatures above the range of general experience. Experimental investigation of creep at high temperatures calls for patience, and well repays forethought and careful organisation.

Many of the characteristic features of creep failure can be demonstrated by experiments at ordinary air temperature. About 1909 I experimented on annealed copper wires, a number of which were used to suspend different weights. The elongations were measured from week to week, and the rate of extension appeared to vary in the exponential manner described by Prof. Kerr. A number of the wires fractured within a year, and the limiting creep strength was estimated to be about 70 per cent. of the value indicated by an ordinary tensile test. In tests at ordinary air temperature, therefore, the limiting creep strength is well above the ordinary yield point.

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Prof. B. P. Haigh, D.Sc.

At ordinary temperatures creep is no source of danger, but, on the other hand, may afford a valuable safeguard against fatigue due to alternating or pulsating stresses. If creep occurs below the fatigue limit, stress concentrations, such as those illustrated in Prof. Coker's well-known experiments with polarised light, may be dissipated before they can cause fatigue. That aspect of the question was investigated by Mr. J. S. Wilson and myself, and was described in a paper read before the British Association at Hull on 7th September, 1922, and published in "Engineering" on the following day. It appears that such creep occurs in mild steel at ordinary air temperature, and materially contributes to the recognised reliability of that metal under fatigue stresses. It will be unfortunate if the search for immunity against creep leads to greater danger from fatigue.

Prof. Kerr makes it clear that the limiting creep stress falls off very rapidly when the temperature reaches a certain zone—so rapidly that a definite narrow range of temperature may fairly be described as the limiting creep temperature. For general safety against both fatigue and creep, it appears desirable that a metal should have a high limiting creep temperature, combined with a certain amount of creep at stresses near the fatigue limit. It may be of interest to note that the fatigue limit of a metal does not usually fall off with increase of temperature as rapidly as the tensile and creep strengths. For that reason, fatigue fractures at high temperatures are not very common.

Dr. W. H. Hatfield: This is an extremely interesting subject, and one upon which we are doing a good deal of work at the Brown-Firth Research Laboratories. Prof. Kerr is really attempting to reduce the phenomenon to a mathematical basis, but I must confess that, at the present time, the data are really much too scanty for this to be attempted. I think the mathematician must wait until the

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Dr. W. H. Hatfield.

investigators have provided a good deal more data. The phenomenon of creep is undoubtedly of fundamental importance, but our experiments here show that on mild steel such material is quite safe under the present factors of safety up to the temperatures at present practically dealt with by designing engineers.

Messrs. H. J. Tapsell, A.C.G.I., and J. Bradley, B.A.: The paper by Prof. Kerr sets out very completely the importance of his subject, and gives a useful review of such published information as is available. He also explains very clearly the phenomenon of creep of materials at high temperatures. If only for these reasons, such a publication is valuable. But in addition he contributes an analysis of existing data obtaining mathematical expressions purporting to fit the facts.

Since the expressions evolved by Prof. Kerr are based on the assumptions that the law of duration is hyperbolic and the law of creep (extension) exponential, it is necessary to see whether these laws are applicable. These are simple mathematical laws, and it would be expected that the phenomena they refer to should also be simple. At least two experimental facts suggest that the phenomena are not so simple as would at first appear to be the case, namely, that in long time tensile creep-tests under constant load the stress is increasing as the extension increases, and also that at some point in the test, local contraction becomes rapidly of chief importance. Results on the more ductile materials show that, previous to the occurrence of local contraction, the elongation is practically uniform over the test length for a considerable ratio of the time occupied in the test. These complex factors do not, however, necessarily indicate that the facts may not be expressed in simple mathematical terms for all practical purposes, but before making use of the analysis given in the paper it is necessary to examine whether additional creep data will support such analysis.

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Messrs. H. J. Tapsell, A.C.G.I., and J. Bradley, B.A.

It may be useful to indicate how far the experimental work at the National Physical Laboratory supports the assumptions upon which Prof. Kerr's analysis is based. Dealing first with the assumed exponential law of creep, it is possible to say that the creep curve appears to be generally of the form given in Fig. 13, but that the initial downward curved part of the main curve may be either practically absent or larger than is actually shown in Fig. 13. Prof. Kerr is aware that for temperatures and stresses just below the creep limit the initial curved part comprises the whole of the curve of extension, the extension ceasing altogether after a time. It is, therefore, not difficult to see that at stresses or temperatures just above the creep limit the curve of extension may show an initial downward curvature. Our experiments show that when the creep limit is only slightly exceeded the initial part is much more prominent than when the limit is greatly exceeded. In the latter case it is practically absent. In addition, the prominence or extent of the initial part depends largely on the material under test. The following table of figures will illustrate this point. Some of the figures are obtained from tests on a nickel-chromium alloy,* and the others from tests on Armco iron:—

ARMCO IRON.

Temperature of test. Degrees C.	Approximate duration of initial part of creep. Days.	Time to fracture (duration). Days.	Remarks.
380	2·4	7·85	Initial part of creep proceeded for nearly one-third of total extension.
360 (and same load as before)	22	59	Initial part proceeded for one-third of total extension.

* "Mechanical Tests at High Temperatures on a Non-Ferrous Alloy of Nickel and Chromium. Engineering, Nov. 13, 20, and Dec. 11, 1925.

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NICKEL-CHROMIUM.

Temperature of test. Degrees C.	Limiting creep stress. Tons per sq. in.	Stress applied in test. Tons per sq. in.	Approximate duration of initial part of creep. Days.	Time to fracture (duration). Days.
500	**24**	**25·25**	**2**	**47**
500	**24**	**28·9**	**1**	**17**
590	16	18·0	1	7
590	16	20·0	Practically absent.	2·5
700	6	6·95	1	11
700	6	7·75	Practically absent.	3·5

The above figures illustrate the difference between the two materials, one of which is notably ductile, and the other rather the reverse at the higher temperatures. Thus it appears that it is generally necessary for Prof. Kerr to add the expression in equation (6) to give the total extension, equation (7).

Prof. Kerr refers on page 342 to the necessity, in considering curve, Fig. 10, "of avoiding that range of very fast testing of the 'minutes and seconds' order in which many effects are introduced that can hardly be expected to fall on a curve shape expressing viscous flow influences." Prof. Kerr does not state what effects are introduced, but one effect would be the rapid rise in temperature over the initial temperature due to the rapid elongation. In short time tests, even those occupying a few hours, the test piece stretches very quickly during the latter part of the test when local contraction occurs, and it is almost impossible to control the temperature. Thus the latter part of the extension, which may account for one-third of the total extension (and possibly the former part, if the yielding on the first application of the load is considerable), takes place at a much faster rate owing to rise in temperature. It seems advisable to ignore tests of less than two or three days duration, especially when these tests are to be used,

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as suggested by Prof. Kerr, to determine the conditions of infinite duration of creep or cessation of creep. This statement tends to criticise the use to which Prof. Kerr suggests putting his analysis. He states that two quite short tests would be sufficient to determine the limiting creep temperature for a given stress. For any fair accuracy in this determination, at least one test of long duration, together with one of short duration, would be necessary to define the true shape of the temperature-duration curve.

In support of the above statement, two curves are given in Fig. 19. They represent actual experimental results. The curve A B C D is a temperature-duration curve. The points marked A, B, and C are observed values for the duration, the point D being estimated from the results of a 70-day test and the knowledge of the total extension at fracture to be expected. The other curve gives the results of the same tests plotted as a velocity-temperature curve. It has been obtained by measuring the steady rate of creep from the extension time curves. This method of plotting has been used for a long time in cases where an approximate steady rate of creep exists, since it has offered the most exact means of determining the creep limit. It is evident from this curve that it is easier to determine where it meets the temperature scale than to determine where the curve through A, B, and C becomes asymptotic to some temperature line. If Prof. Kerr in proposing two short time tests means something of the order of the one-day and five-days tests, he virtually only determines the points A and B, Fig. 19, and then assumes a hyperbolic curve through these points. If the times have not been accurately determined, and the temperatures not maintained constant, then it seems very doubtful whether the true temperature limit of creep is obtainable. If, also, one of the two tests is not quite representative of the material under the particular testing conditions, then the method fails. We have made use of the hyperbolic assumption in our tests for deter-

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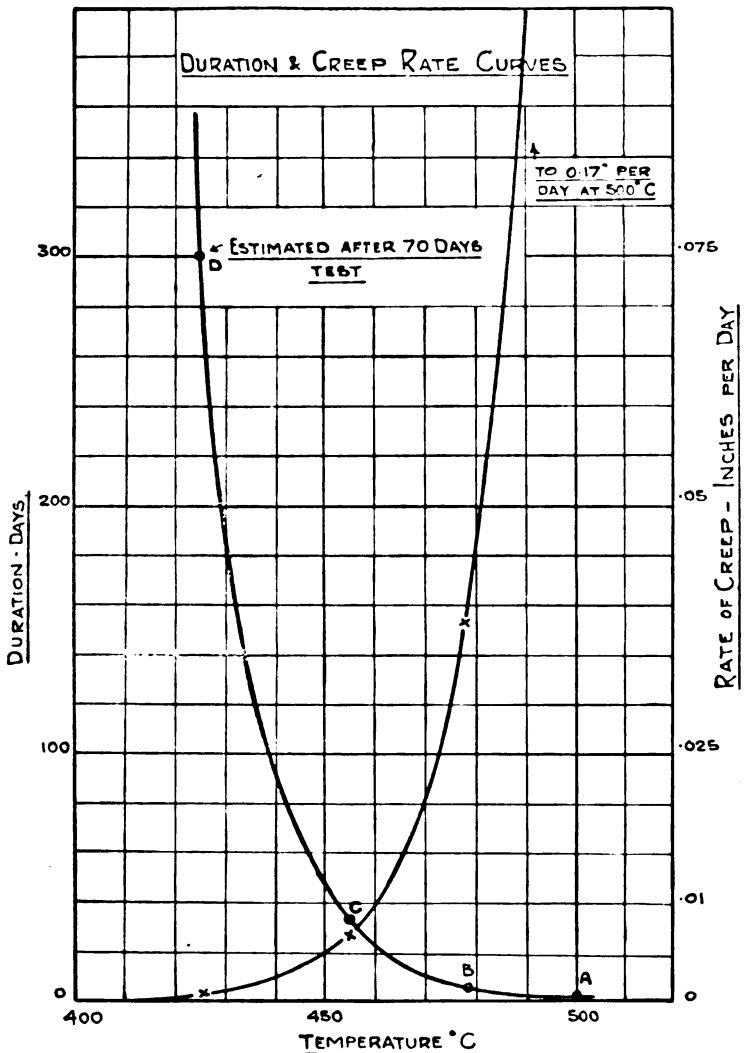

Fig. 19.

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mining the most suitable temperatures for a given set of tests, much in the same way as it is used for determining suitable stresses for application in ordinary fatigue testing, but, as in fatigue testing, we have approached the limiting conditions as closely as possible in order to determine them with greater accuracy.

With regard to the progressive stress method of test, we have felt that, until it has been settled that in general no strain hardening occurs in the higher temperature field, it is not advisable to adopt this method. Our results show that at least in some cases some strain hardening occurs in that field near the point where the limiting creep stress more nearly approaches the ordinary ultimate stress.

Dr. E. M. Horsburgh, M.A. (Member): In the first part of this paper Prof. Kerr gives a valuable summary of the present state of knowledge of the creep of metals. In his discussion of the results which have been obtained, much turns on the ultimate shape of the temperature-duration curves. From the geometrical point of view, this is an inquiry into whether or not there is an asymptote parallel to the duration axis, and, if so, where it is situated. Prof. Kerr keeps the issue clearly before the reader, and indicates that, though reasonable conclusions can be drawn in certain mathematical equations when a variable becomes infinite, yet it is quite a different matter to argue about infinity from physical observations which deal only with relatively small values of the variables involved.

With regard to the representation of the equation $H=\frac{bt+k}{1-at}$ by Fig. 10, it might perhaps have been more convenient to keep to the familiar and helpful mathematical conventions of measuring outwards from the origin, setting the independent variable t along the horizontal, and the dependent variable H along the vertical axis. Thus, to avoid confusion, on replacing

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Prof. Kerr's H and t by y and x, the equation becomes $y = \frac{bx+k}{1-ax}$, and with the usual conventions the curve passes from the point (o, k), concave upwards, to the asymptote at $x = \frac{1}{a}$. Now k is presumably a selected value, so we may translate to a new $x-$axis through (o, k). This gives $y = k + \eta$ where η is the new $y-$co-ordinate. Hence, on substituting, we have $\eta - ax\eta = (b+ka)x$, or $\frac{\eta}{x} - a\eta = b + ka$. So if we plot η against $\frac{\eta}{x}$ the curve is transformed into a straight line, and it is a simple matter to find the most suitable values of a and b for any set of observations. An alternative method would be to plot the reciprocal of η against the reciprocal of x.

If H were required to be plotted horizontally, it would seem better to have solved for t in terms of H. This would give $x = \frac{y-k}{b+ay}$, or on interchanging x and y so as to have y as a dependent variable, we have $y = \frac{x-k}{b+ax}$ in which as $x \to \infty$ $y \to \frac{1}{a}$ as before. This form of curve occurs in many types of investigation, both in the behaviour of materials and in other subjects, and always introduces this difficulty as to the ultimate value of the quantity represented by the dependent variable when the independent variable becomes infinite.

In any attempt to speculate on the physical reason for creep an explanation would require to be given of phenomena such as those investigated by Prof. Lea at ordinary temperatures, with an extension to the more strongly marked results at high temperatures. Thus the explanation would seem to depend on the effect of the strain on the crystalline granules of the metallic specimen. The arrangements of the atoms in the cubic space lattices of α- and γ-iron are known, and each forms a system in stable equilibrium under normal conditions.

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Accordingly when the crystalline granules are strained, they would tend to creep back to an equilibrium position when the stress was withdrawn. Such flow might take considerable time, as in the case of a viscous fluid, though the flow of a crystalline body differs fundamentally from that of a viscous fluid. When a metal test bar is being strained, say, under a steady load, certain granules yield more than others. Thus, apparently, the specimen is not at once in internal equilibrium, but is being deformed slowly and irregularly while certain granules are taking up the extra load due to the yield of certain other granules. This would result in either a slow extension of the specimen, ceasing ultimately, *i.e.*, converging on a limit as equilibrium was obtained, or else, if equilibrium were not obtained, continuing till failure of the bar. At high temperatures such phenomena would be more marked. On heating the specimen the atoms are further energised, and rendered more easily disturbed, and so the flow should be more easy at higher temperatures, which is, of course, in accordance with observation.

The very sharp drop which is seen in temperature-stress curves, after a certain temperature has been reached, is very striking. Can this be due to some temperature rearrangement of structure in the granules? If so, the specimen would then be in an unstable internal equilibrium, and hence would be peculiarly liable to deformation under load. The temperatures, however, in these steels at which the phenomena occur are well below the Ar_1 point. But if reference be made to an article in "Engineering," 23rd October, 1925 (Dr. R. H. Greaves and Mr. J. A. Jones; Research Dept., Woolwich), it will be seen that in impact tests on steels at high temperatures there are distinct minima in the neighbourhood of 600 degrees C. This at least suggests the possibility of some form of rearrangement of the structure at a comparatively low temperature. If so, this would help to explain the mysterious sharp drop in the temperature-stress curves.

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Prof. James Muir, D.Sc.

Prof. JAMES MUIR, D.Sc.: I wish to express my admiration of the manner in which Prof. Kerr has presented this resumé and analysis of so great a mass of important experimental work. I desire to make no comment on the most interesting attempt he has made to gather the results obtained by various investigators, using different methods of experiment, into one common mathematical method of representation, other than to state that I feel sure the attempt was well worth making, that it will prove of great service from a practical point of view, and that it may help towards an elucidation of the physical causes which give rise to the phenomenon of creep.

There is one feature of the phenomenon to which Prof. Kerr has not referred, and which should not be lost sight of, namely, that there is both forward and backward creeping. If a hot bar of metal be subjected to a pull sufficient to produce continued creeping extension, and if the load be removed, then for quite a considerable time after the load is removed the bar will continue to shorten in length, the rate of backward creeping becoming slower and slower with the lapse of time. This phenomenon of forward and backward creeping has, of course, been known for a very long time—for more than 60 years—and a mathematical representation of the effect was given by Boltzmann as long ago as 1874. A short account of this early work will be found in Clerk Maxwell's article "On the Constitution of Bodies" in the "Encyclopædia Britannica," or in Vol. II of his "Collected Papers." An interesting way (described by Maxwell) of demonstrating the effect at ordinary temperatures, I have used as a lecture table experiment since 1906. If a wire be suspended (a rubber cord is better for lecture purposes) and its lower end twisted through, say, two turns to the right, held there for a little, then untwisted and turned through one turn to the left; then if the wire is allowed to come to its position of equilibrium, it will first show a slight twist to the left which will slowly disappear, and will be followed by a creep to the right. It is as if the wire remem-

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Prof. James Muir, D.Sc.

bered it had received a twist to the right before receiving the twist to the left.

Although these old experiments have no very obvious connection with the failure of metals by creep, I doubt if Chevenard's experiments of 1919 ought to be regarded as the "first direct investigation in the creep field." For example, the late Prof. Hopkinson, of Cambridge, published a paper "On the Elastic Properties of Steel at High Temperatures" in the Proceedings of the Royal Society for June, 1905 (reproduced in "Engineering," September, 1905). Hopkinson's experiments were of short duration, and were for temperatures up to 800 degrees C. or 1,470 degrees F. He paid special attention to the forward and the backward creeping under low stress. The backward creeping, after the removal of load, was surprisingly large. The conclusion arrived at was that the elastic properties of hot steel were similar in nature to those of materials like glass, rubber, or freshly overstrained iron or steel—substances of very imperfect elasticity.

Perhaps I might question the statement made at the foot of page 331 in Prof. Kerr's paper, that Lea is the only investigator who has examined creep at normal temperatures. This might pass if confined to work dealing with ultimate fracture. Creep at ordinary temperatures was investigated by, I think, Ewing, in 1895, and by myself to a slight extent in a paper "On the Recovery of Iron from Overstrain."* The statement that Lea observed creep for over an hour at practically all stresses should surely be confined to stresses beyond the yield point or elastic limit.

It may be of service to point out, with reference to the comments made with regard to the constants a and b of equation (1), page 344, that a is $\frac{1}{(T_o - T_c)}$ and b is $\frac{d}{(T_o - T_c)}$, where d is the distance of the y axis from the vertical asymptote of the rectangular hyperbola.

* Phil. Trans. Royal Society, 1899, vol. 193. A. p. 1.

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If an understanding of the physical causes of creep is to be reached, it is probable that the simpler question must first be tackled, as to why it is that a single crystal of iron (or of aluminium, as first investigated by Carpenter) has practically no elasticity at all, while the aggregate of crystals which go to make up a bar of the material may have very perfect elasticity up to its yield point.

Dr. D. H. INGALL: I have read Prof. Kerr's paper with pleasure, and consider it to be a distinct addition to the study of the subject. It is always an advantage to have a subject reviewed and analysed with the mathematical ability shown in the paper, an ability which, unfortunately, does not often fall to the lot of the metallurgist. As a metallurgist, somewhat of the type indicated by Prof. Kerr, *i.e.*, one desiring to know the physical reason and meaning of creep, I wish to point out that, without at all underestimating the value of general results and conclusions, the real truth must not be lost in the apparent truth. I feel that the present case is somewhat comparable to the general gas laws of physical chemistry, which, though so valuable, are apparent truths, and had they been left alone as such would have masked the real truth as revealed in the kinetic theory and Van de Waal's work. In the present case it is probably quite incorrect to take a single term of creep to explain the phenomena taking place at both high and low temperatures, as they are not comparable. At the lower temperatures the creep effect is probably due to crystalline slip *only* in the material; at higher temperatures it is probably due to *both* crystalline slip and viscous flow taking place simultaneously, and hence a mathematical analysis of the one will not be strictly comparable to the other. I think that the critical inflection temperature brought out in my work marks the change from the one phenomenon to the other. At temperatures below the critical inflection temperature, the creep effect, though depending on time,

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Dr. D. H. Ingall.
is not concerned with infinite time, *i.e.*, it will cease, and for any given temperature, any stress below the fundamental breaking stress of that temperature will cause creep but will never rupture the material. Above the critical inflection temperature the effect is probably far more insidious, and while it may be possible to estimate "safe stresses" for "given temperatures" to cover the ordinary life of apparatus and machines, yet actually very small loads will probably always cause rupture if given sufficient time.

There is one other important point, namely, the *condition* of the material, and it is with this that my work has been chiefly concerned. It is, of course, well known that a cold-worked metal, which is hard and strong, can be made softer and weaker by annealing. Modern processes of fabrication often turn out articles in the partly cold-worked condition. What will happen if these articles be adapted to appliances working at elevated temperatures? It will be quite evident to all engineers that the possibility of softening in service is a factor of paramount importance in calculations of strength of parts, and it should be remembered that all high-temperature tests which have been carried out by the application of temperature first and the stress afterwards, only give data with regard to a softened material at the given temperature.

Mr. JAMES M. MACAULAY, B.Sc. (Associate Member): I have read this paper with genuine pleasure and real profit. Prof. Kerr clearly shows that the phenomenon of creep in materials is of the greatest practical importance, especially in connection with high-temperature duties. It would appear that creep considerations may also afford light on some obscure problems that arise in the manufacture of such component parts as welded press-work fittings and certain forms of castings.

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Mr. James M. Macaulay, B.Sc.

I have in mind some experiences with aeroplane press-work fittings during the war. An immense amount of trouble developed in the making of certain tubular-strut fittings, which required considerable welding in their assembly. The fittings were made and allowed to cool one day, and appeared perfectly sound; the next day or later they were found to be cracked. Indeed, a field officer was subsequently sent over from France to report that this particular fitting was giving way on the machines there, and a special court-martial was called to consider the matter. It was not very difficult to understand how stress developed during manufacture (and the design was modified), but the fact that rupture did not take place until a considerable period after the fittings had cooled to air temperature was puzzling. I take it that the creep-time factor operated here, and have no doubt Prof. Kerr includes some such consideration when he refers to the "possible deformation of the material under working conditions." I have been wondering whether an investigation of the strength of welded joints, in the light of creep failure, might not be practically fruitful.

It is difficult to imagine a more useful piece of work than a paper such as this. The collation and analysis of the investigations of a number of more or less contemporary investigators are of supreme value. It is a pity that more such guiding work is not done, as the analysis and codification of new scientific and technical knowledge is inadequate to the present-day rate of progress and modern requirements. In this connection scientific and technical institutions have a real role to fill, and it is encouraging to find this Institution, with the splendid help of Prof. Kerr, indicating how it should be done.

Mr. E. F. Spanner (Member): Prof. Kerr frames a warning which cannot be neglected by any engineer whose designs compel him to subject materials to stresses while they are

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Mr. E. F. Spanner.
at a high temperature. It is useless to rely upon the old strength-temperature curves obtained by methods neglecting the importance of the time factor. Put in plain terms, but without attaching any particular significance to the figures mentioned, it is folly to design machinery or apparatus in which material will be actually subjected to, say, 5 tons per square inch, on the assumption that the ultimate strength of the material, at the particular temperature to which the part is to be subjected, will be 20 tons per square inch, if the material at that particular temperature will actually start to creep at any stress above 15 tons per square inch. Obviously, by neglecting the importance of the time factor, a designer unwittingly accepts a much lower factor of safety, which, in the hypothetical case taken, is three instead of four.

Considering that such part of the plant or mechanism might be confining some force of tremendous potentialities, were it permitted to escape, it is more than certain that every responsible engineer will be anxious to have the full truth, rather than be deluded into a sense of false security by having only a partial knowledge of the facts.

To-day we are witnessing the efforts of those to whom steam still represents the source of power *par excellence* to invade regions of higher pressures and higher temperatures. There are valuable gains to be reaped from successful achievement in these directions, but pioneers can afford to neglect no single phase of the important subject outlined in Prof. Kerr's paper, if they are to avoid disaster. The explosion of a boiler or some other portion of a machinery installation, containing superheated steam at high pressure, would be calamitous indeed, not only in its effect on those in the vicinity, but in the effect which such an occurrence would inevitably produce in the atmosphere in which further progress would have then to be made.

Papers such as Prof. Kerr's are valuable to a degree not

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always appreciated by the average designer, to whom they sometimes merely present themselves as offering fresh obstacles to advance. Every designer is familiar with the sense of vexation and annoyance which is felt when the fact that he must make allowance for the inherent limitations of the materials with which he is working involves him in the necessity of increasing his thicknesses, thus disturbing the balance of his design, often even to the extent of causing him to strike out on a fresh line altogether. The realisation that the accepted ultimate strength-temperature curve must be appreciably modified to bring it within the safe creep limit cannot be otherwise than decidedly unpalatable, but the thanks of those anxious to make progress must needless be as hearty as would be those of a man warned of a hole in the road, into which he would have fallen but for timely advice given him.

As to the latter part of Prof. Kerr's paper, and the extraordinary amount of detailed information it contains on recent experiments, I might venture the opinion that while Prof. Kerr has been animated by the most helpful motives towards engineers in the effort he has made to reduce known experimental facts to forms which will enable them to be of the readiest use for purposes of design, there is need for a very great deal more experimental work before his formulæ can be accepted as fully satisfactory. There is always a grave danger in the acceptance of formulæ based on a very limited series of experiments, for such formulæ may become so firmly established as to render their correction, in the light of more definite information, a matter of difficulty, while it is even within the bounds of possibility that further research may be retarded by the feeling that there is nothing fresh to be learnt.

It has often occurred to me that such a state of affairs has already been exemplified in the work of those who have devoted much time to the elucidation of problems concerned

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Mr. E. F. Spanner.

with the resistances met with by a body in moving through water, and in the devising of the best means for maintaining the motion of that body, while the premature crystallisation of ideas on the subject of ship strength has similarly obscured the need for considerable further research in this latter field. This, however, is by the way. With these reservations, to which Prof Kerr himself subscribes in his paper, the formulæ put forward appear to offer a very suitable means by which, pending fuller data, the deriving of creep limit values of an order likely to be extremely valuable in design work may be readily carried out.

Prof. Kerr has recognised the fact that a mass of curves and similar data, or alternatively the carrying out of a long series of experiments on individual materials, are neither likely to be of great value to the engineer at the moment, and his formulæ should undoubtedly be very welcome to every engineer who is already faced with difficult temperature design problems.

It is greatly to be hoped that more papers of a like character will be contributed from time to time to our technical institutions. Engineers and shipbuilders are very busy men; they rarely have the time to dig and delve in the proceedings of those specialist societies before whom such papers as those to which Prof. Kerr has referred are read, and as a consequence there is another "time lag" to be recorded, *i.e.*, that between the date when those occupied in specialised research work begin to arrive at knowledge of fresh factors affecting materials or methods, and the date when such knowledge reaches the ears of those surrounded with the everyday work of engineering design, although the latter are generally the only people who can make definite use of such new data. Such a paper as Prof. Kerr's is invaluable in reducing this particular "time lag."

Incidentally, research workers are only human, and the work itself is often dry and monotonous. They are well

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entitled to the satisfaction of feeling that the value of their labours is fully appreciated by those who have them to thank for the erection of the signposts and protecting rails which mark and make safe the path of progress.

Mr. R. W. Bailey: Prof. Kerr has a very worthy object in the endeavour to represent the phenomenon of creep symbolically, and he is to be congratulated for the method of treatment he has presented. It is necessary, however, to question the validity of his method of determining the limiting temperature T_c, Fig. 10. Prof. Kerr rightly remarks upon the careful character and duration of Dickenson's work, and although that investigator found by logarithmic plotting that his research gave no indication of such a limiting temperature, it is ingeniously argued that such a method of plotting may be misleading. It can hardly be suggested, however, that such was the case in Dickenson's work when the results for all the metals tested are considered. It seems to me that if the assumption made by Prof. Kerr has reasonable justification, it could not fail to be exhibited by logarithmic plotting much more convincingly; but such is not the case, and the value of T_c determined in the manner suggested must, therefore, be doubted.

It is very unfortunate that other investigators have not followed Dickenson in employing logarithmic plotting of either the duration of a test or the rate of creep. The opinion may be ventured that if this had been done, different and more reliable conclusions would have been reached. I have examined published data in this manner, and have been forced to the conclusion that, in most cases, investigators have mistaken the limit of accuracy of their apparatus or method for the cessation of creep, and the so-called limiting creep stresses at present published cannot be given a more useful interpretation than this.

The following example may be given as representative.

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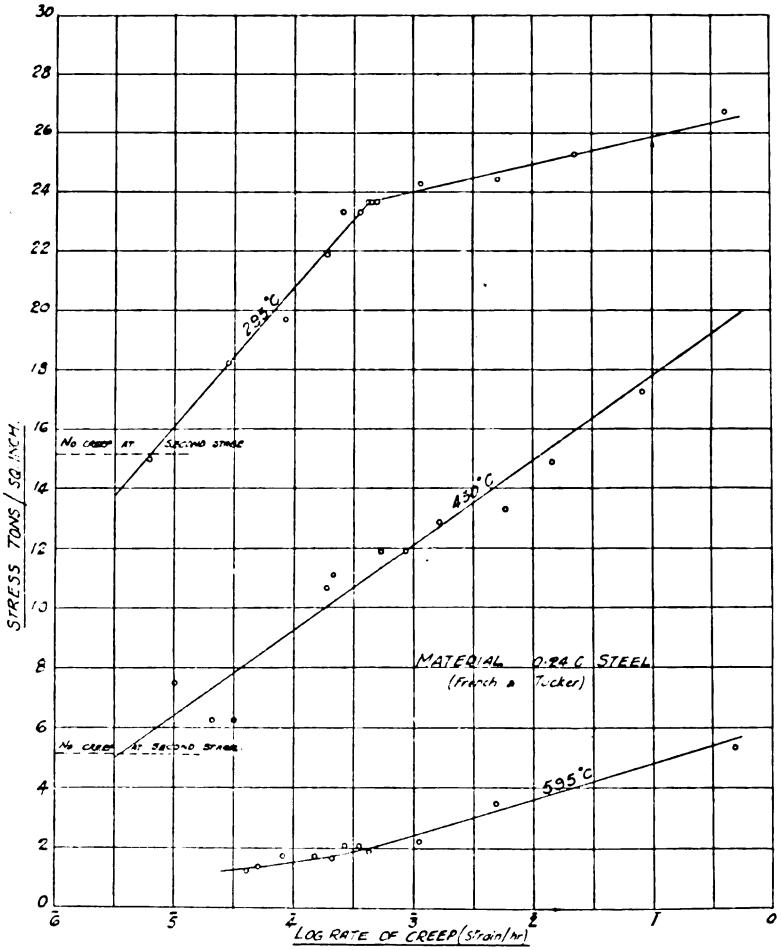

Fig. 20.

Fig. 20 gives the results obtained by French and Tucker,* which I plotted, with the logarithm of the rate of creep as

* H. J. French and W. A. Tucker, "Flow in a Low-Carbon Steel at Various Temperatures," Technologic Paper 296; Bureau of Standards, Washington.

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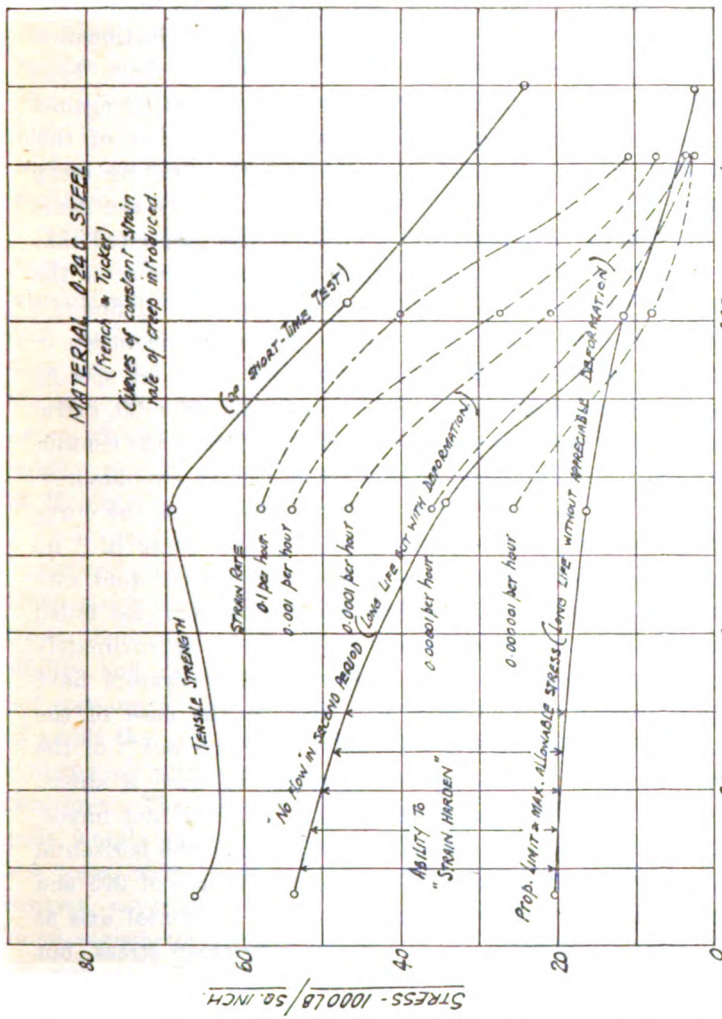

Fig. 21.

abscissæ, and Fig. 21 reproduces one of their diagrams with an addition made by myself. It should be pointed out that the rate of creep is that for the second stage, marked "steady creep rate" in Fig. 13. The limiting creep stresses for the

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Mr. R. W. Bailey.

second stage, as estimated by the investigators, are marked in Fig. 20, and it will be noted that there is no justification whatever for the values chosen. The authors have been misled, in common with others, because they plotted against rate (or duration) instead of against the logarithm of this quantity. It is important to note that the limiting creep stresses obtained cut the graphs at approximately the same rate of creep, and it must be assumed in the case cited that this rate, namely, approximately 0·000005 strain/hour, is the limit of accuracy of the investigation in question. I find the work of other investigators to lead to the same conclusion in an equally striking manner. If values of stress at specific rates of creep are taken from the three graphs of Fig. 20, extrapolated only as far as the log. rate of creep = 6, then the contour lines for constant rates of creep shown on Fig. 21 are obtained. It will be observed that these contour curves cross the curve for proportional limit, and indicate that the curve of "no creep in the second stage" is really a curve of constant rate of creep, namely, the rate which the investigators just failed to detect. This, as already noted, appears to be approximately 0·000005. It cannot be said that these investigators have found limiting creep stresses, and only in the case of the temperature of 595 degrees C. is a "flattening out" of the graph indicated, suggesting the existence of such a stress. But this is below the proportional limit, and it is not impossible that the graph may become asymptotic to the horizontal axis at zero stress. The graphs for temperatures of 295 and 430 degrees C. may become parallel to the horizontal axis at some stress which would be a true limiting creep stress, but it is clear that a much higher degree of sensitivity would be needed for such stresses to be detected. The same conclusions are obtained from other investigators' work. I have previously suggested* that there is some reason to think that the propor-

* Discussion of "The Effect of Low and High Temperatures on Materials," F. C. Lea, Proc. Inst. of Mechanical Engineers, 1924.

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tional limit, *i.e.*, the stress at which it is assumed there is no plastic distortion, may be the limiting creep stress, and in this respect it would appear that Fahrenwald's diagram, Fig. 7 may be a satisfactory representation, but clearly French and Tucker's work indicates that creep takes place, at the higher temperatures at least, at lower stresses than the proportional limit.

Sufficient has been said to indicate that of the data published so far there is very little which would support the method followed by Prof. Kerr in finding his limiting temperature, and the majority is on the side of Dickenson in showing that limiting values have not yet been found. I consider that there are sound reasons connected with the mechanism of creep which support Dickenson's view, and a note upon the subject is to be presented at the next meeting of the Institute of Metals.

It is necessary to raise the question whether, from the engineers' point of view, it is of importance to have a limiting creep stress or a limiting temperature at a given stress below which there is no creep. In view of the experimental inaccessibility and extreme uncertainties of these quantities, I do not consider it to be so, but that it is much more satisfactory to admit the existence of creep, and in the absence of definite evidence of such limits to assume that it occurs at all temperatures. The engineer's problem for a given material is then quite simple and safe. From the results of a comparatively few tests carried out over reasonable times at, say, three-stresses, covering a range embracing stresses now used and found satisfactory and lower values, a graph can be plotted for each stress between temperature and the logarithm of the rate of creep for the "second stage" or the duration to fracture, but preferably the former. Fig. 22 represents such a diagram, with the lines for stresses f_1, f_2, and f_3 extrapolated beyond the experimental values. If now experience has shown that at a temperature T_1 a stress f_1 is satisfactory, and

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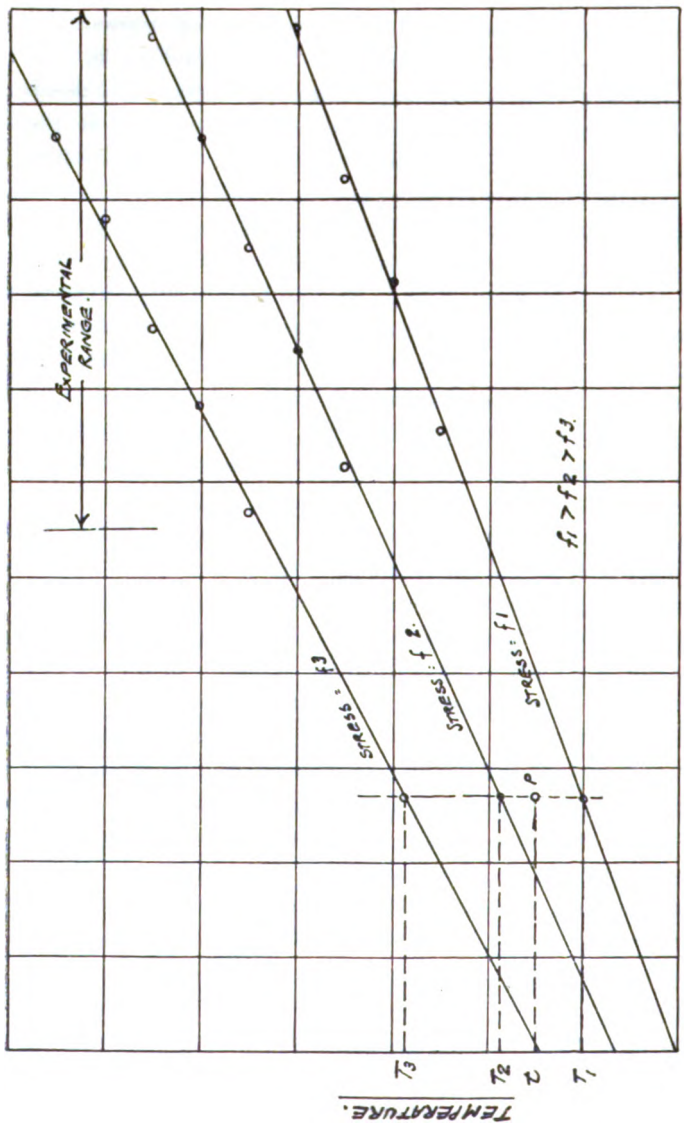

Fig. 22.

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it is desired to operate at a higher temperature t with equal satisfaction, the working stress necessary will be that represented by the point P. The magnitude of this stress would be obtained, of course, by plotting the relation between f and T as given by the values f_1, f_2, and f_3 and T_1, T_2, and T_3, and interpolating for t. There is reason to think that if the result thus obtained errs at all it will do so on the side of safety.

There is sound metallurgical reason for an opinion that the previous history of a metal as to its working and treatment considerably affects its creep behaviour, and it is, therefore, essential that data be obtained upon metal precisely as used. Thus, for example, if a steel casting is considered, tests should be made upon material from a casting the proportions and treatment of which are representative of what will be employed. It is suggested that, by observing this requirement in the material tested, the procedure indicated by the foregoing is, in the present state of knowledge, the most satisfactory and rational to follow, where engineers wish to proceed to higher temperatures with existing kinds of apparatus. Also, new apparatus or materials could be dealt with by means of the diagram represented by Fig. 22, the stress being determined for the required working temperature, and the log. rate of creep shown by cases in other materials to be satisfactory.

These suggestions are put forward not as a criticism of Prof. Kerr's treatment, which is analytically correct, but because I am of the opinion that existing data do not justify the interpretation made of them in finding a limiting temperature for a given stress below which creep does not occur. And until more refined data are available which do give an indication of the existence and magnitude of such a temperature, the safe and practical course to pursue is one such as I have indicated.

Prof. KERR: The discussion that has revolved around this subject of creep proves, by its length and variety, the interest and importance of the problems involved. The array of com-

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petent critics is somewhat disconcerting, and it is with trepidation that I face the task of dealing with the multitude of points that have been raised. Perhaps it might be permissible to say, at the outset, that the nature of the discussion tends to support my charge regarding the confusion of the subject, as nearly every conceivable opinion—definite and indefinite—and a fair range of data—agreeable and disagreeable—make their appearance. Extreme variety in these matters is, no doubt, a good thing so far as the progress of the subject itself is concerned; but it is hardly a great advantage as regards ease of assimilation by those who have to utilise the essential results.

In the paper a certain classification of subject matter was attempted; a review of experimental work was followed by an analysis of the same, while the closing section included some remarks on test procedure, and emphasised the importance of the subject in engineering design. The endeavour may be made to deal with the discussion in some corresponding order, since a consideration of the contributions in sequence would necessarily entail rather sudden and distinctly erratic changes in points of view.

In the experimental review, I credited Chevenard with the first leading work on failure by creep. It was to be expected that this would be questioned, since it is always difficult to say who was the first investigator in a fundamental matter of this kind. The choice must depend to some extent on the attitude taken up; whether creep is being considered or failure by creep; or whether the review is of a temperature field in which the phenomenon has a secondary or a primary influence. Prof. Muir and Dr. Brown both submit facts of some importance in this connection. It could have been assumed as certain that many investigators had detected the more direct consequences of creep in the normal temperature ranges, and Prof. Muir indicates that physicists have long been aware of the facts. His statement regarding forward and backward

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creeping is interesting, and should be noticed. Dr. Brown explains that Prof. Barr investigated the influence of the rate of loading on strength many years ago, and this reference is certainly worth having.

These earlier investigations indicated, on the whole and at the most, only minor changes of strength due to rates of loading; and while Dr. Brown refers to the recent work on creep as merely the "logical conclusion" to that which he cites, I take the liberty of suggesting that, while the "conclusion" is certainly striking, the "logic" is somewhat obscure. It takes a highly powerful form of logic to argue a reduction of strength, by creep, amounting to $\frac{9}{10}$ths, say, at 1,000 degrees F., from an observed reduction of $\frac{1}{10}$th, say, at 100 degrees F., more especially in view of Dr. Brown's emphatic reference to the manner in which the creep limit at normal temperatures responds to courses in "physical training." In any case, neither the original investigators nor the logicians foretold it; and since it represents the all-important fact to engineers, and the essential aspect of the subject as I have treated it, I see no strong reason to alter my system of dating progress from the work of Chevenard. The main aspects of failure by creep lie in the high-temperature field—and probably the only chance of elucidating the phenomena rests on work of this type—and have only been discovered, in their fulness, by the high-temperature investigations of recent years; and not assumed, nor expected, as a consequence of the low-temperature work of the past.

Mr. MacNicoll refers to the late Prof. Longbottom's work on non-ferrous metals at high temperatures, and describes this briefly. The work is, of course, well known, but while it involved long period soaking at these elevated temperatures, this does not in any way correspond to long period stressing under similar conditions. So far as I know, or can discover, Prof. Longbottom had not investigated creep as it is herein understood. If he had done so, I should certainly have quoted

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it, for his work was always notable for accuracy and thoroughness.

Since the paper made rather a point of presenting a résumé of all the important facts that had been experimentally established in this subject, it is natural to ask how far the discussion contributes to the sum total of such information by providing new data or unearthing material that had been overlooked. Prof. Mellanby's contribution is especially welcome on this account, since he submits information on cast iron, which metal had not been referred to in the paper, simply because no information was available. It will be seen from Prof. Mellanby's Fig. 16 that the main features of his results for this material are in keeping with those presented for others, and hence fill an important gap in the catalogue of metals subject to long period tests. The reference to Mr. Donaldson's work on the effect of long period annealing, and Prof. Mellanby's own quoted results of a like type, are of interest, although departing somewhat from the strict lines of the present subject.

Dr. Brown's excellent and lengthy contribution contains a great amount of information which well repays thoughtful reading, but it would hardly be possible to deal adequately or fully with it here. To some extent it confuses the issue, since fatigue effects enter largely into the treatment. He sets out with a definition of a high-grade engineering material. The writing of such definitions is an excellent exercise, and if we had a direct postal service to the Laboratories of Nature they might prove highly effective. Otherwise the idealistic grouping of several remarkable qualities is apt to create a feeling of discontent with what is likely to prove but a rough approximation thereto. Dr. Brown also makes considerable reference to the creep limits at normal temperatures, and the influence of "training" on the results obtained. These points are all very true, but they tend to limit the view to features that are already well appreciated. Whether the creep limit is

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two tons below the ultimate, or can be raised two tons above it, is not of serious consequence in engineering. It is certain that, in the normal ranges, the earlier adventures of a specimen have considerable influence on the time and character of its demise. But the question seems yet unanswered whether any such adventures are of real moment in a field in which creep failure is definite, significant, and important. The evidence seems against any appreciable influence of the kind. Both Mr. Bailey and Dr. Ingall refer to the same point, and the former advances the statement that there are sound metallurgical reasons for the belief that the previous history of a metal considerably affects its creep behaviour. It is not, however, stated whether such reasons apply in the high-temperature field; but I think it will be agreed, generally, that since a creep limit of any importance is the result of a long time high-temperature test, the test itself is a process of complete annealing that wipes out the past "history." It is highly improbable that creep limits in the upper temperature regions will be noticeably affected by pre-treatment.

I judge that the part of Dr. Brown's contribution which is of the greatest importance lies in his discussion of creep and fatigue effects in association. As he points out, this raises a "big question"; and, if Prof. Haigh's remarks on the same subject are taken in conjunction, the complexity of the question will be fairly obvious. There is no doubt that this combined problem requires study. Its present position is exceedingly confused. Prof. Lea has elsewhere shown how well the fatigue limit is maintained, even with high mean stresses, at temperature values where the creep limit has become very low. Dr. Brown apparently indicates that under fluctuating stress of high mean values new creep limits enter into the question, while Prof. Haigh appears to believe that creep contributes to the reliability of a material under fatigue. It is clear, however, that a full consideration of fatigue plus creep would carry us far beyond the range of the

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present subject matter. Another paper would be necessary for its complete review, and it may be hoped that Dr. Brown, in the near future, will be induced to take up the subject for our benefit.

Prof. Haigh also refers to some experiments on the creep of copper wires over periods up to a year, from which the creep limit was estimated at about 70 per cent. of the ultimate. Taken in conjunction with some of Dr. Brown's remarks, it would appear that, at normal temperatures, the limiting value may be anywhere around the direct strength, but is apparently well above the yield point. As a general result, this may be noticed as supporting my criticism of Fahrenwald's conclusions. Against this, however, we have Mr. Bailey's citation of French and Tucker's work—which is, by the way, an acceptable addition to the bibliography of our subject. Mr. Bailey himself, like Fahrenwald, appears to favour the proportionality limit as the creep limit, but states that French and Tucker obtained even lower values. Experimental evidence, on the whole, seems contrary to this. Prof. Muir corrects my somewhat ambiguous reference to Lea's observations of creep at all stresses, and rightly explains that this should read "at all stresses beyond the yield." It follows that he, at least, would be rather surprised at the contention made on the strength of French and Tucker's work. It would seem best, on the whole, to assume, as a general guidance, that the creep limit is above the proportionality limit; well above it at normal temperatures, although probably only slightly above it in the higher ranges. The proportionality limit is itself a somewhat indefinite value in the upper temperature field.

Mr. Bonn refers to the use of electrolytic iron in the Holzwarth gas turbine, and to the appearance of a curve for this material in one of my lantern slides. The curve is from Chevenard's series, and is shown along with the others of that series in Fig. 23. It will be observed that it presents the

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lowest creep limit of any of the materials included, and on this score it is hardly possible to discover the reason for its claimed superiority for gas-turbine blading. It is doubtful whether the experience in this direction has conclusively

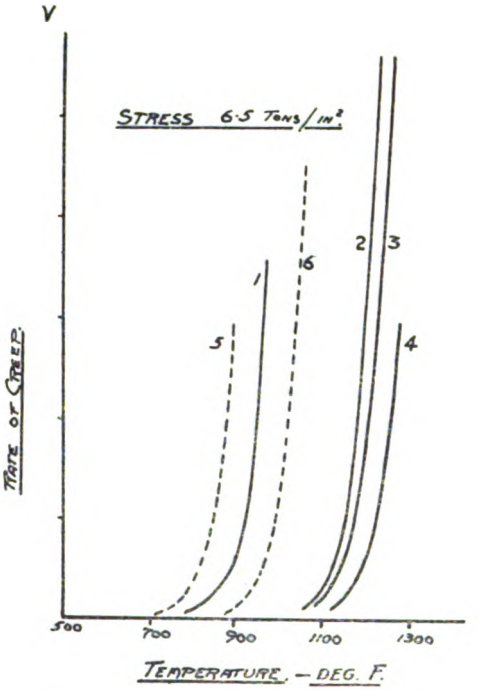

Fig. 23.—Creep Rate Curves—Chevenard.

1. Nickel (cast) (99% Ni.). Annealed at 1,300° F.
2. Nickel-Chromium Alloy (15% Cr.). Annealed at 1,650° F.
3. Nickel-Chromium Alloy (22·6% Cr.). Annealed at 1,650° F.
4. Nickel-Chromium-Tungsten Alloy (9% Cr., 5·8% Ni.). Annealed at 1,650° F.
5. Electrolytic Iron. Annealed at 1,300° F.
6. Nickel-Chrome Steel (0·3% C., 4·2% Ni., 1·6% Cr.). Annealed at 1,300° F.

proved that electrolytic iron is the most suitable material for the purpose.

The discussion has not produced any very direct references to specific failures in practice due to creep. It is hardly pos-

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sible to believe that such have not occurred. Mr. MacNicoll states a case in which the "slight trouble" experienced at a pressure of 800 lbs. and a temperature of 840 degrees F. was not apparently due to creep, but a few further details regarding the nature of the trouble would have been of considerable interest. Mr. Macaulay refers to the failure of tubular strut fittings after welding and cooling. It is rather difficult to see how creep effects would explain this, and it would appear rather more probable that the welding process was at fault in creating the possibility of excessive temperature stresses that would intensify as cooling proceeded. Creep effects, on the other hand, would diminish as the part cooled.

One or two contributors refer to the general phenomena of creep, and outline conceptions of the physical processes involved in such an action. Some others aver that it is yet too early for the mild form of analysis to which I have subjected the experimental data of the subject. If this is the case, and the data are considered inadequate for that simple duty, how much less adequate must they be for the discussion of physical causes? Still, speculation—of any kind—is always interesting. Dr. Ingall restates his conclusions regarding the critical inflection temperature, with crystalline slip only at temperatures below this, and crystalline slip, together with viscous flow, above it. There is no doubt that Dr. Ingall's own investigations provide some justification for such a point of view, but, considering the whole range of experimental data available, it seems that such a conception must be classified as one of the "apparent truths," mildly condemned by Dr. Ingall in another sentence. There is no very clear evidence of definite critical temperatures dividing the creep and non-creep fields, although the rapid manner in which creep becomes important over a narrow temperature zone provides partial support for the idea.

Dr. Horsburgh tends also to think in terms of a critical temperature, and he tentatively develops a point of view

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regarding the mechanism of creep which is not without interest, and which, in its stride, embraces the forward and backward creeping referred to by Prof. Muir. Dr. Horsburgh's outline is typically that of the mathematician seeking to account for all the observed facts, and he nowhere loses sight of them, or of their interrelations. With one statement he makes, namely, "... though the flow of a crystalline body differs fundamentally from that of a viscous fluid," I must express agreement. In the literature of creep there is a strong tendency to create an idea of the similarity of these effects, which is hardly a sound point of view. It is best at this stage to realise that no satisfactory explanation is really possible, and that the proper theory will, no doubt, explain many other things besides creep when it arrives. But before it does arrive, the point raised by Prof. Muir, as to why a single iron crystal has no elasticity, while an aggregate has perfect elasticity, will need attention; and the first stages toward the complete theory will have to include this apparently much simpler, and more fundamental, fact.

I come now to the criticism that has been offered of the attempt made in the paper at a process of experimental analysis. Some attack in this quarter was to be expected, as investigators—and particularly investigators on materials—have hardly ever recognised any intermediate field between the mere tabular or graphical representation of direct facts on the one hand, and the "rigorous and comprehensive" theoretical discussion on the other. But why should they not? The immediate use of nearly all materials testing is to guide engineering design. Its ultimate aim may be of a much higher order, but the engineer is hardly able to wait until the ultimate end is achieved. Those who appreciate present-day tendencies in heat-engine practice—and the contributions of Mr. J. S. Brown, Mr. Spanner, Dr. Hatfield, and Mr. MacNicoll show that they are numerous—will understand the supreme importance of the subject of creep to all concerned

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Prof. William Kerr, Ph.D., A.R.T.C.
with the problems of advance therein. It might be asked whether they believe that the experimental work which has passed under review in this paper, in all its variety of method and results, provides clear and definitive guidance regarding the essential creep limits. To the engineering designer these limiting values are the all-important measures of the creep effect that he must avoid. Ultimate strengths will serve his purpose in the low-temperature field—in spite of Dr. Brown's assertion that they are of no direct importance to the designer. But in the high-temperature ranges—the important modern field of development—creep limits must take their place. The problem is to get these limits in the easiest fashion, by the simplest principles, and in such a way that the vagaries of experimental method will be duly assessed. I submitted the simple analysis as a line of solution suitable for this purpose, not with the slightest belief that it was final, but with the hope that it would illustrate the necessity for the co-ordination of results in such materials testing. There is no more active line of research to-day, but it is to be feared that the production of data at times overwhelms those whose duty it is to employ them, and certainly tends to render a large proportion of the gross results unusable until the process of co-ordination has been effected. Mr. Spanner's excellent note on this theme should be noticed; while Mr. Bonn, in what is, as I understand it, a reference to common habits in the presentation of experimental results, uses the term "intellectual snobbishness." This must be reckoned a little severe, but there is probably just that moiety of truth in it that renders it the more telling.

The function of the analysis was, then, co-ordination. It had nothing to do with the basic causes of the phenomenon it discussed; but it claimed to advance an important question that must arise in the business of investigating that phenomenon quantitatively, on different materials and by different methods. Such must be its justification to those who

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infer generally that the attempt is premature. Their criticism is only legitimate if it be assumed that any co-ordinating scheme must necessarily be final. Mr. Spanner is really the only commentator who raises a genuine point here by his remark that such methods tend at times to an easy belief that the subject is complete. But they can only have such a tendency with those who do not keep in touch with developments, and I am afraid the call of "new lamps for old" will always pass unheeded in these quarters.

The hyperbolic temperature-duration relationship receives a certain amount of notice. Prof. Muir gives a note on the value of the constant b in equation (2) which really amounts to defining the vertical asymptote of the curve; while Dr. Horsburgh describes at length the usual mathematical methods and conventions concerning the equation to the hyperbola and its graphical representation. I hardly think that the slight differences thereby indicated constitute a "breach of the conventions"; one is surely permitted to deal with a simple rectangular hyperbola in any suitable way; and the curve may be concave upwards or downwards, with H vertical or horizontal, without affecting the consequences. But sufficient justification for the method I adopted lies in the fact that it is directly connected with the usual experimental forms. The hyperbola very frequently appears in practical problems in this way, and there is not the slightest necessity to translate to new variables or new axes, either to present it clearly or to interpret it soundly. However, if my critics accept the *type* of curve, I am perfectly willing to grant full freedom as to the form of expression, secure in the belief that they can only reach the same conclusions.

Mr. J. S. Brown agrees that the hyperbolic relation is more rational than the logarithmic mode of plotting results—for which it is really a substitute—and finds that it suits his own experimental work reasonably well, although he feels sure there will be occasional exceptions. I feel very sure of this also,

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but whether the exceptions may be due to the approximately accurate law or to the approximately accurate experiments is another question. The experimental technique involved in this class of investigation must be of a very high order before great consistency in the results can be claimed, and one main reason for my belief in the advantages of a simple geometrical relationship in the data of this subject lay in a feeling that the extant information hardly justified any greater elaboration. The hyperbolic law is, however, only an approximation, presumed to be the most serviceable because it automatically expresses a limit value which is apparently a strong feature of all the experimental results. Very accurate work, such as that for which Messrs. Tapsell and Bradley are responsible, will no doubt disclose divergencies, but whether these are greater than the normal experimental error, or so great as to render extremely lengthy tests an absolute necessity, is not yet proved by the evidence at hand.

Mr. Bailey is rather strongly against the hyperbolic law, and equally strong in favour of logarithmic plotting, as followed by Dickenson. I have referred in the paper to the misleading nature of logarithmic plotting as a general method, and need add little further. It is a method of "flattening" a curve, and not, in general, a mode of analysis. It has been much used since Osborne Reynolds first employed it, but I am afraid it is also frequently misused. If it does not give a straight line, it is not of great service. In the present connection, if it does give a straight line it cannot express a limit; and if it indicates a limit it ceases to be a straight line, and is almost unintelligible. Mr. Bailey contends that of the data so far published there is little to support the hyperbolic method of finding "limiting" temperatures, and much to support the view of "no limit." I believe the same might be said of fatigue; but the whole practical conception of fatigue is based on the idea of a limit value, and, similarly, practical requirements will necessitate the assumption of a creep limit, the

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while the reality thereof undergoes discussion from all angles. The whole mass of experimental evidence goes to show that there is a value below which creep is of little consequence, and nothing more is necessary to ensure the acceptance and formulation of a limit for practical work. It is the necessity to meet this certain demand that renders the hyperbolic method of discussion superior to the logarithmic.

The above hardly does full justice to Mr. Bailey's contribution, which is of a valuable and constructive nature. His treatment and plotting of French and Tucker's results should be noticed, and his Fig. 21 should be accepted in lieu of Fig. 7 of the paper (Fahrenwald's diagram). It would almost appear to be the original of the latter, and is much clearer and more impressive. It is obvious that French and Tucker's work should have had a place in the experimental review, and I regret not having been familiar with it. Mr. Bailey also provides a method of examining creep data for the determination of safe conditions. This is a proposed alternative to the creep limit method for the engineering problem, and involves the double assumption that creep will persist and that a small allowable rate of creep may be made the criterion of judgment. The process involves the extrapolation of log. lines, and on this matter I have already committed myself. At the same time Mr. Bailey's method is of considerable interest, and has the merit of being strictly in line with his general ideas.

The contribution from Messrs. Tapsell and Bradley is of considerable importance. I agree entirely with their remark that the phenomena are not so simple as the laws I have used would suggest; but if these laws satisfy the salient facts, they may be considered to meet the purpose for which they were proposed. The remarks made on the subject of the initial forms of the creep curves are rather significant. It appears, from the experimental work of Messrs. Tapsell and Bradley, that, just beyond the creep limit, the initial portion of the curve,

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which, in the paper, is considered a minor feature, may be rather prominent. This fact is illustrated by figures for Armco iron, which, in contrast with comparative values for nickel-chromium, show a considerable initial effect.

At this point we may notice also that Mr. Brown objects to the long period failure being descriptively classified as creep failure, and points out that, with cast iron and some non-ferrous materials, no creep distortion may be displayed at failure. In conjunction with Messrs. Tapsell and Bradley's considerations, it follows that the creep curve may, with different materials, either have no existence or may vary in its form. It must be pointed out, however, in so far as this line of criticism affects the analysis, that the form of the creep curve is of little or no importance in the discussion of creep limits. One essential aspect of the data under review lay in the similarity of the relationship between the creep limit curve and the ultimate strength curve for all materials. It seems clear that the material fails under long duration tests, whatever may be the form, or the formlessness, of the distortion; some changes of a like order occur whether the extensometer can record them or not. Now, in the representation of creep limits, as I have carried it out, the influence is really covered by the factor a in the hyberbolic relation, and not by the exponential law of creep, which is mainly used to assess the margin of error in certain experimental methods. In so far as the exponential law may prove incomplete, it only reflects to a secondary extent on these margins. The law itself may, if necessary, be considered a law of change rather than one of creep, without in any sense destroying its usefulness as a means of examination analytically. If each material has a characteristic law of change, the effect of this is included entire in the value of a, which, therefore, covers the peculiarities of the material. The available data, and particularly Dickenson's, support the exponential law very fully, but in view of Messrs. Tapsell and Bradley's remarks it may be

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believed that variations occur. These variations will probably be covered by some such addition as I have suggested in equation (6).

It must be admitted, however, that the variations referred to may reflect to some extent on methods of examination by short time tests; and the point made here by Messrs. Tapsell and Bradley would appear legitimate. Any departures from the hyperbolic law may be a consequence of variations of the law of change or creep within the creep field. Since, however, these changes are admittedly in the early stages of the phenomenon, it does not appear impossible to incorporate them in a method of analysis which would still permit the avoidance of very lengthy tests in the determination of approximate creep limits. I do not think that the extrapolation of long period creep-rate curves, as in Messrs. Tapsell and Bradley's Fig. 19, is any more valid than a method based on short time tests and a proper appreciation of curve forms.

Messrs. Tapsell and Bradley also express some dubiety regarding the influence of strain hardening on the validity of the progressive stress method, and it is valuable to know that they have found evidence regarding this in the higher strength ranges. Even with this, however, I believe that, with some allowance for the essentially high results that it gives, the progressive stress method provides a sound procedure for the determination of creep limits as they are required in practice.

Mr. Clark is the only contributor who comments on the creep limit curve, and he has apparently found the equation thereto of a satisfactory order when applied to data obtained by determining creep limits from readings of an Ames dial. I doubt, however, whether such a method, entailing the observation of movements of the straining head of the machine, can be considered of great accuracy, and it would have been an advantage to know how the creep limits, as so determined, compared with the curves estab-

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Prof. William Kerr, Ph.D., A.R.T.C.

lished directly by the progressive stress method customarily used in his machine. Mr. Clark also discusses very fully the temperature measurement question, raised briefly by my passing reference to Spring and Kanter's paper. He very neatly establishes the fact that the variations detected by these workers involve rather serious temperature gradients in cases, which naturally tends to reflect on their own conclusions. It is certainly all to the good that such questions should be fully ventilated, since it is obvious that in creep determinations the measurement of temperature is of supreme importance; and Mr. Clark's discussion of this problem is, therefore, very welcome.

Many remarks have been made on the general incidence of this subject of creep on engineering design, and I am glad that this aspect has been fully emphasised. Dr. Hatfield apparently infers that the factors of safety at present in use are adequate for the temperature conditions met with nowadays. Mr. Brown says much the same thing, but also indicates the real issue, which is, shortly, that engineers are not satisfied with the present temperature conditions, and desire strongly to proceed beyond them. Mr. MacNicoll and Mr. Spanner enlarge on the same theme, and on the whole it is clear that the warnings I gave in this respect have been accepted as not in the least overdrawn.

I feel that this reply has become overlong, but that is mainly a consequence of the very considerable discussion that has arisen. The number, extent, and value of the contributions made are hardly fully represented by my efforts to extract the salient features; but I am gratified at the attention given to the subject which I have had the pleasure of introducing. Not a few contributors express themselves generously regarding my attempts to review, collate, and condense the experimental data on creep failure, and I appreciate these remarks fully, and return my sincere thanks therefor.

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THE WERKSPOOR DIESEL ENGINE.

By G. J. Lugt.

26th January, 1926.

Your Council have done me the honour of inviting me to read a paper before your Institution on the Werkspoor Diesel Engine, and you will probably expect me to begin with a description of the engine as it is to-day. This, however, would be like reading to you the last chapter of a book, the first chapters of which are—from a technical point of view—the more interesting. It is good to know that the romance ends happily, but the development of the plot is what really matters. I shall, therefore, begin my paper with the history of the Werkspoor single-acting engine, which I regard as a finished volume, and then cut the pages of the first chapter of the second volume, namely, that of the double-acting engine.

Werkspoor, of Amsterdam, Holland, whose works are situated on a site where shipbuilding has been going on ever since the latter part of the seventeenth century, and upon which an engine works was established as long ago as 1827, took a licence in the year 1902, for building Diesel engines, from the firm that built the first engine of this type, the M.A.N. Company, of Augsburg. The first stationary engines to be constructed were of the A-frame type which is familiar to everybody, but when larger powers and higher speeds were desired standard practice was departed from, and I think Werkspoor were the first to introduce the through-going steel columns, tying the bedplate to the cylinders, which design

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has now become almost universal practice. The first sea-going engines built by Werkspoor, in 1908, were auxiliary engines of about 200 h.p., which were fitted to schooners, and are still giving excellent service. They were not directly reversible, but were provided with reversible blade propellers of an improved type. Similar propellers have since been applied to higher-powered ships.

In 1909, the first marine engine was ordered by the Anglo-Saxon Petroleum Co. for the tanker "Vulcanus," a vessel of 1,200 tons deadweight. This engine may be considered the Adam in the line of evolution of the marine Diesel engine, and it, therefore, deserves a little closer inspection, especially as many of the features embodied in this engine may still be found in the Werkspoor engine of to-day; in fact they are present in a good many engines of other types. The "Vulcanus" engine, Fig. 1, was a six-cylinder motor of the crosshead type, designed to develop 600 i.h.p. at a normal speed of 175 r.p.m. It was fitted with forced lubrication, and was, therefore, entirely enclosed, but large steel-plate doors gave easy access to the interior of the crank-case. The principal parts were a bedplate, with cast-iron frame columns and a cylinder block, all three being rigidly held together by through-going bolts. In the first engine is seen the characteristic marine type of motor which is now so well known. The reversing gear consisted of two parallel camshafts, supported in brackets hinged on a third shaft, from which shaft they derived their rotary motion. This third shaft was driven by a system of connecting rods from a half-speed shaft, geared to the main crankshaft. This system of driving the camshaft has proved very satisfactory in practice, and the design has not since been departed from. The air compressor was link driven from one of the main crossheads, and it was placed at the back of the main frames.

The "Vulcanus" engine was eminently successful, and it is in operation to-day. A number of orders for larger engines

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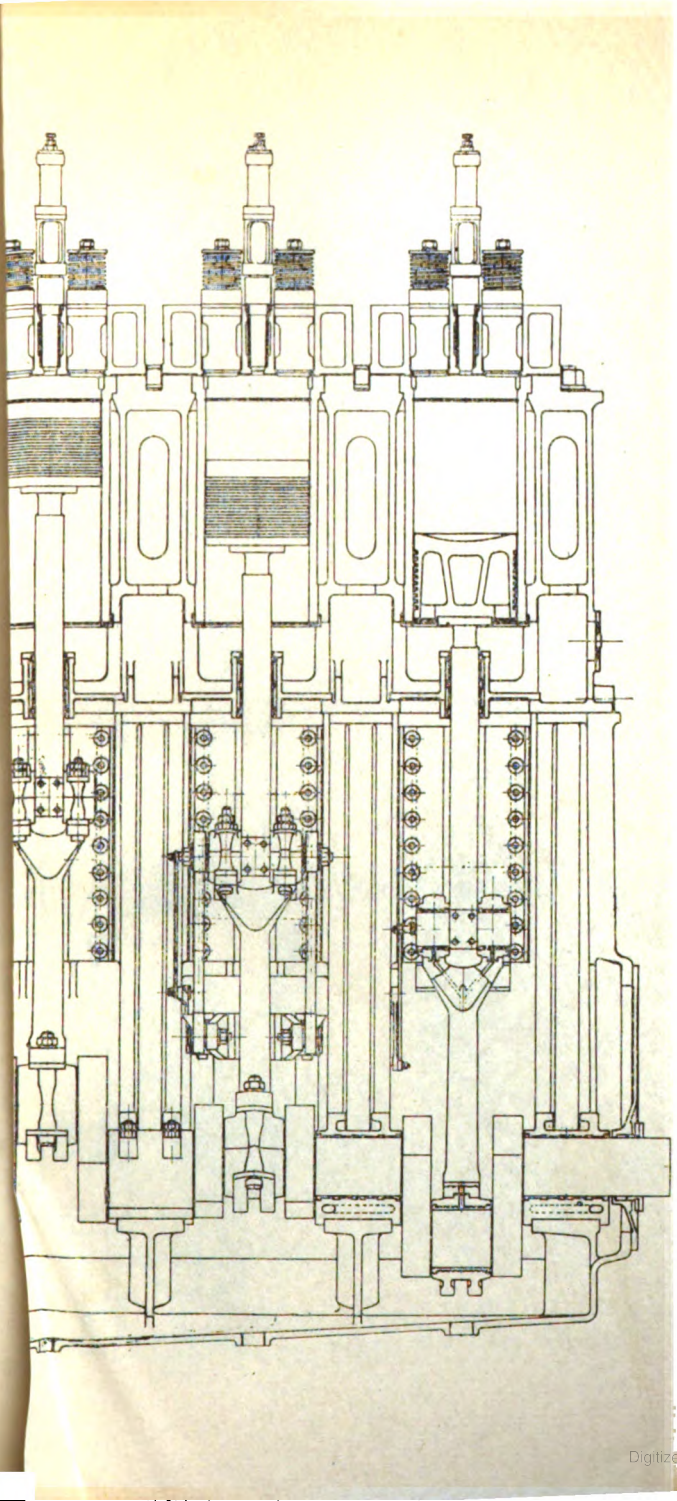

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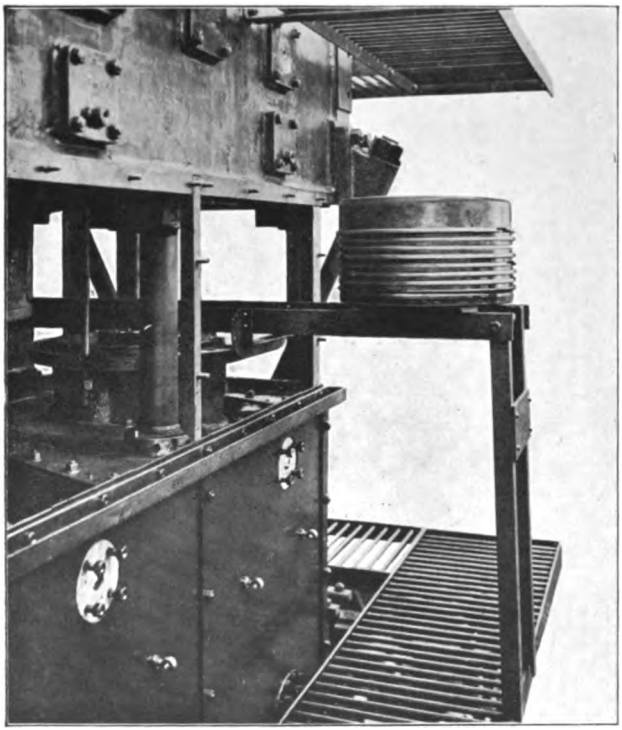

Fig. 2.

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followed, and a period of extreme activity in marine Diesel-engine building set in. Later, the construction of the engine was changed considerably, on principles which were at the time considered to be essential in order to ensure the future success of this type of propelling machinery. The leading principle adopted was to keep the engine as much on the lines of the old type of steam-engine as possible, and to keep out of the design everything that might scare off the engineer accustomed to steam-engine practice. This change resulted in doing away with the forced-lubrication system and the adoption of open framing, so as to give the engineers in charge an opportunity of feeling such moving parts as were accessible. It was rightly considered that accessibility should be the leading feature of the engine, not only for the reciprocating parts within the crank-case but also for the piston and its rings, which are perhaps among the most important and delicate parts of the engine. The system of dismantling the piston which has since become closely associated with the Werkspoor engine was then devised, Fig. 2. The cylinder liner is provided with a detachable extension, bolted on to the liner with a number of tap bolts. This extension can be lowered, leaving the piston entirely open to view, when the crank is in its bottom dead centre. The piston rings can then be inspected, cleaned, or renewed, and if necessary the piston can be detached from the piston rod and taken out. All this is easily done in an hour's time, and one day suffices to overhaul all the pistons of a six-cylinder engine.

This labour-saving device has always strongly appealed to sea-going engineers, for it enables them to maintain the pistons in good working order, even if very little time is available for overhauling. It must be conceded that the many improvements since introduced in the construction of the pistons and piston rings have diminished perhaps the prime importance of the device, for a piston which is constructed on correct lines and is properly lubricated needs little attention nowadays; but

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I am thinking of the earlier days of the marine Diesel engine, when much had yet to be found out about pistons. The troubles with the first pistons were mainly due to two causes; firstly, the sticking or gumming up of piston rings, and secondly, the method of attachment of the piston to the piston rod. The sticking of the rings caused the piston to blow, with consequent rapid wear of the cylinder liners, and excessive consumption of lubricating oil, with a dirty engine and engine-room. Such sticking of rings cannot be attributed to any one cause, indeed there are several causes which may combine in producing the effect; consequently it is only when they are all eliminated that a satisfactory working piston is obtained. The first essential is good and efficient combustion, with no after-burning and its detrimental effect on the lubricating oil. The piston-cooling water, especially if it is sea-water, should be kept well away from the cylinder walls. The rings should have the proper clearance in their grooves, and they should be placed at a suitable distance away from the piston crown, in a well-cooled part of the piston wall. The principal thing is not that the ring should be at a certain minimum distance from the combustion centre, but that the lubricated cylinder wall be not exposed when the fuel is still being injected. It has, therefore, nothing to do with the bore, neither is it a constant, as is sometimes thought, but a function of the stroke. Concerning the stroke and bore of the engine, I may point out that the stroke-bore ratio of Werkspoor engines was, up till a few years ago, greater than that of any other type. As Werkspoor's first ships were in the majority single-screw, it was realised from the beginning that the speed of the engine should be low, a decision which resulted in a long-stroke engine being adopted in order to attain a certain piston speed, from about 800 to 900 feet per minute, which was then thought and is still considered to be a safe speed.

The method of attaching the piston to the rod caused a great deal of trouble in the early days of the construction of

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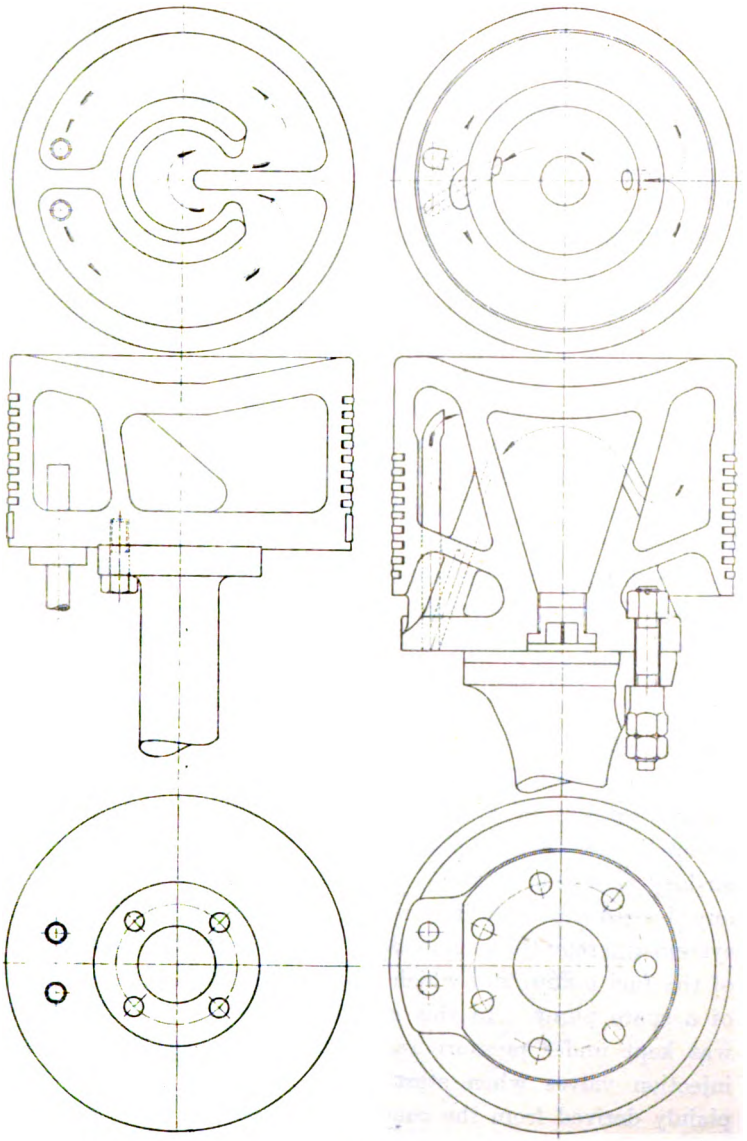

OLD TYPE PISTON. Fig. 3. NEW TYPE PISTON.

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marine oil engines. It was then calculated that only the inertia forces, plus the friction of the piston in the cylinder, were to be taken into account, and the connecting bolts were dimensioned accordingly. However, it was soon proved that these bolts were too weak, and it was only by increasing the number and size of the connecting bolts and the diameter of the piston-rod flange that the trouble was overcome, Fig. 3.

With reference to the general appearance of these earlier engines, it will be seen that accessibility was very much increased by adopting an entirely open framing with through-bolts, without any intermediate cast-iron columns steadied by a number of diagonal stays. The side thrust was taken up by a cast-iron column, placed in the centre line of the cylinder. It was rigidly bolted to the bedplate, but could slide where, at its upper part, it was attached to the cylinder block or beam, thus leaving the steel columns free to expand under the influence of the combustion pressure. It may be remarked that from the very beginning the importance of a diaphragm between the crank-case and the space under the cylinders was realised as a feature of design, which is now considered as absolutely essential by all builders of four-cycle engines, Fig. 4.

Something quite novel in these engines was the fuel pump. It is a fact, well known to every Diesel engineer, that if an engine refuses to start, nine times out of ten the fuel pump is not working as it ought; usually there is an air-lock or a leaky valve. As a marine engine must start at any desired moment, it was considered necessary to devise a system whereby the engine should be more or less independent of the fuel pump, and which also allowed for the introduction of a spare pump. In this system a certain quantity of fuel was kept under pressure ready to be conveyed to the fuel-injection valves when starting the engine. This idea was plainly derived from the conditions which prevail in a steam-ship, namely, a feed pump—with a spare pump—and a boiler

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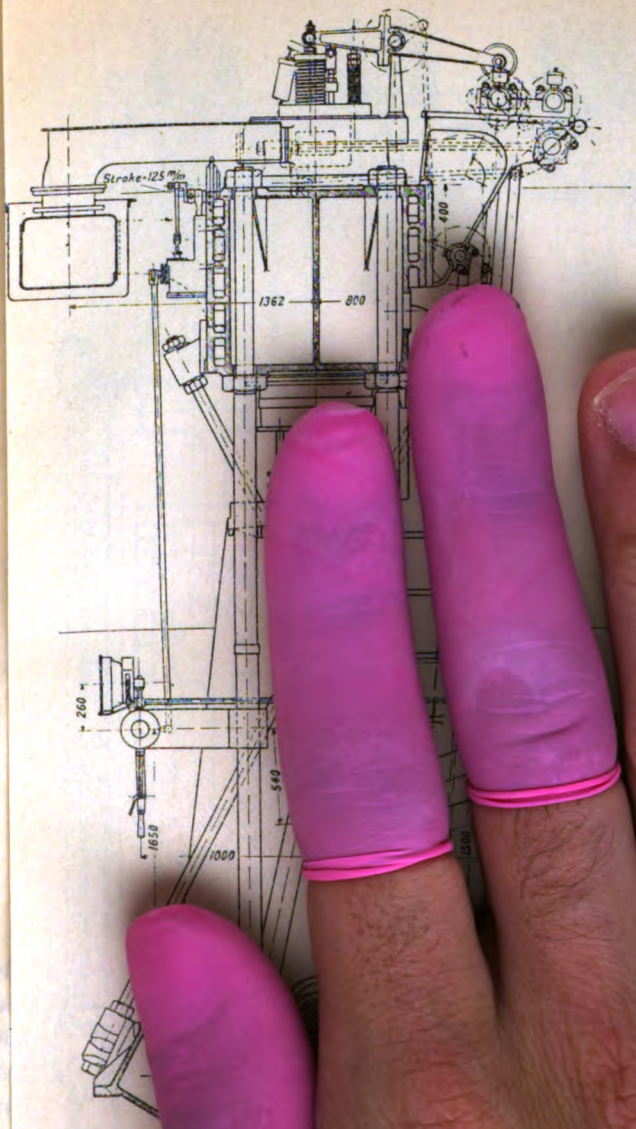

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full of steam, ready to give off its latent energy when called upon to do so.

The system then used is still employed, and although improved in several details, it is essentially the same in principle, Fig. 5. An H.P. fuel pump of very ample capacity delivers the fuel into a reservoir, which is placed at a height

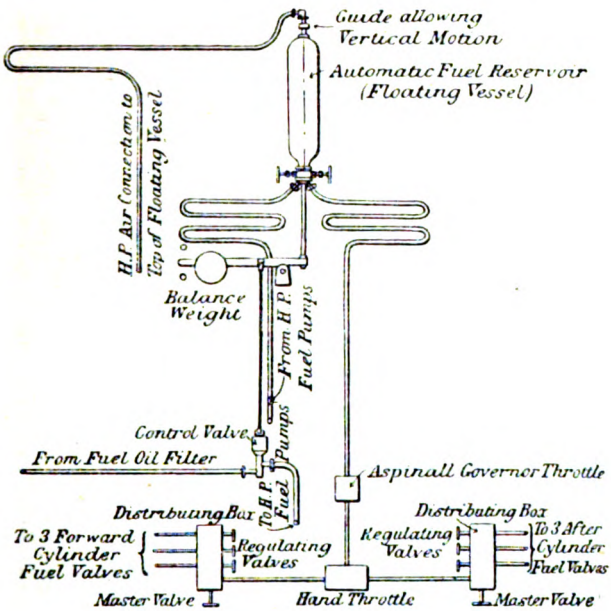

Fig. 5.

of about 10 feet above the top of the engine, whence the oil can flow by gravity through distributing valves to the fuel-injection valves. The top of the reservoir is connected to the injection-air system, so that the pressure on the oil is, therefore, the same as the pressure in the fuel-valve casings. The reservoir is attached to one end of a double-armed balance lever, with a counterweight on the other end, Fig. 6. When the reservoir is about two-thirds full, the weight of it causes

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the balance lever to turn on its fulcrum, which motion closes a valve in the suction pipe of the fuel pump. When a certain quantity of fuel is used, the reservoir rises again, the valve is reopened, and the fuel pump refills the reservoir. In practice the movement of the reservoir is negligible, for it remains in a certain position of equilibrium, in which the valve in the suction pipe is opened so much that the quantity of fuel delivered is equal to the total quantity used by the engine. This total quantity, which determines the speed of the engine, can be regulated by a throttle valve in the delivery pipe leading from the reservoir to the distribution boxes. In the latter are needle-valves so adjusted that each cylinder receives an equal amount of fuel, which ensures that the engine is working at full load when the throttle valve is completely opened up. It is, therefore, impossible to overload the engine, and the quantity of fuel going to each cylinder is determined by the head of the reservoir above the level of the needles, a constant, and the opening up of the distribution needle-valves, another constant. If for some reason one needle-valve is closed, the quantity of fuel going to other cylinders is, therefore, not changed, and no overloading can take place. Should the fuel pump stop, then the fuel contents of the H.P. reservoir will be sufficient for the engine for a further 15 minutes or so. If something goes wrong with the pump, it is made apparent by the automatic slowing down of the engine when the fuel level in the reservoir has fallen below a certain point. When this occurs the engineer will have ample time to put in the spare fuel-pump, after which he can overhaul the main fuel-pump at leisure.

This system is both simple and reliable, and it makes certain that the engine will start on all six cylinders when manœuvring. It also makes the engineer feel quite sure of his engine. Incidentally it reduces the complexity of the ordinary fuel-pump, with its several plungers and numerous valves, levers, springs, etc., to one very substantial and simple pump, in

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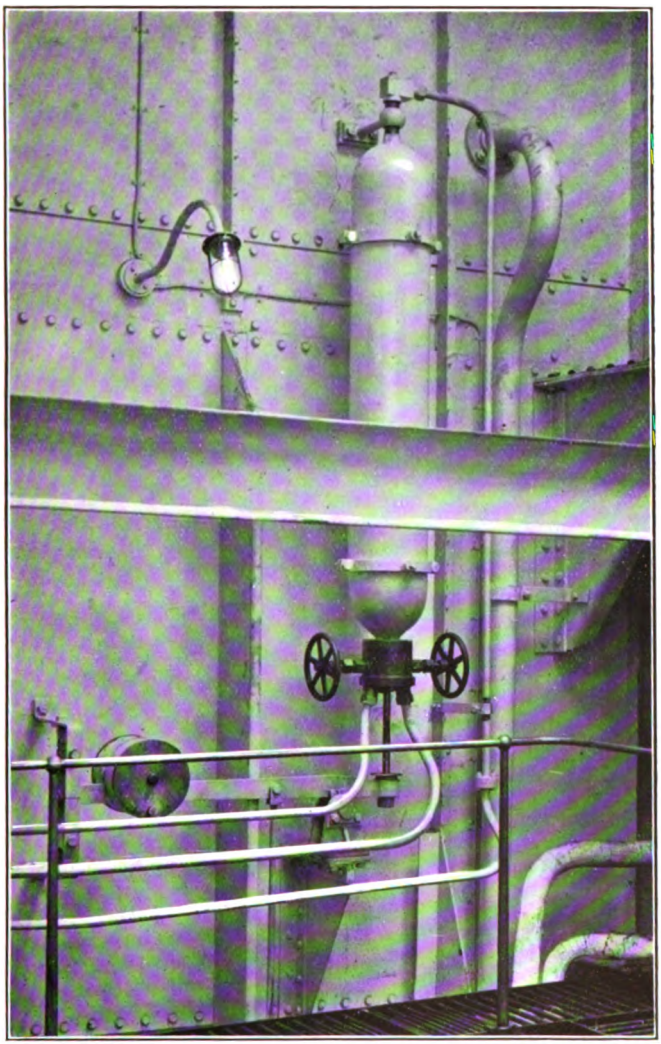

Fig. 6.

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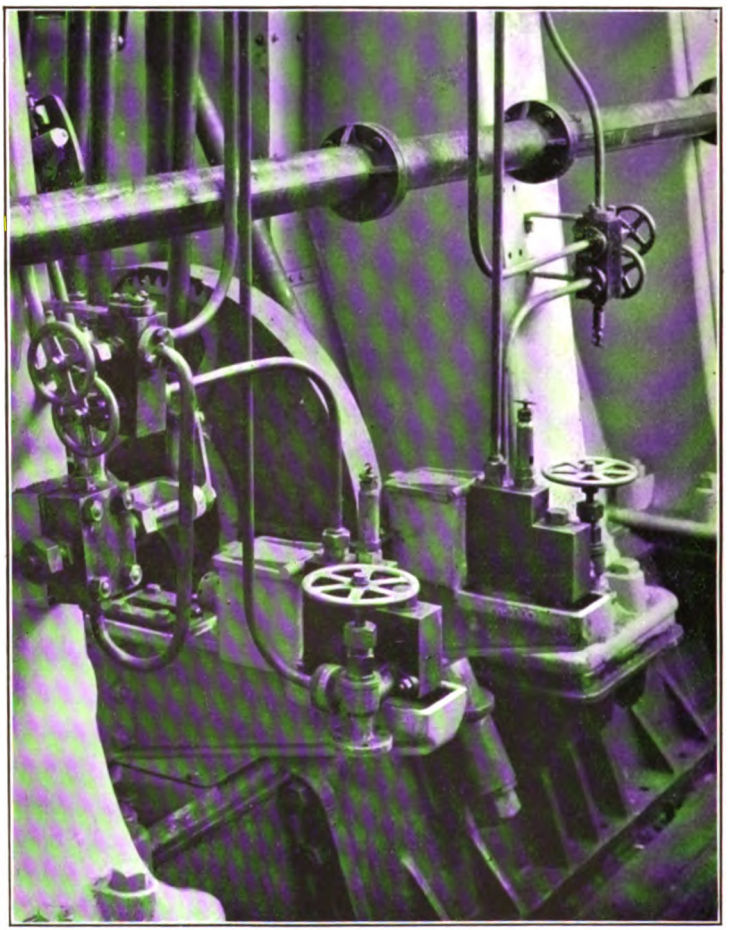

Fig. 7a.

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which steel balls are used for valves. The capacity of this pump is such that even should a serious leak past the valves take place it would not affect the working of the engine, Figs. 7a and 7b.

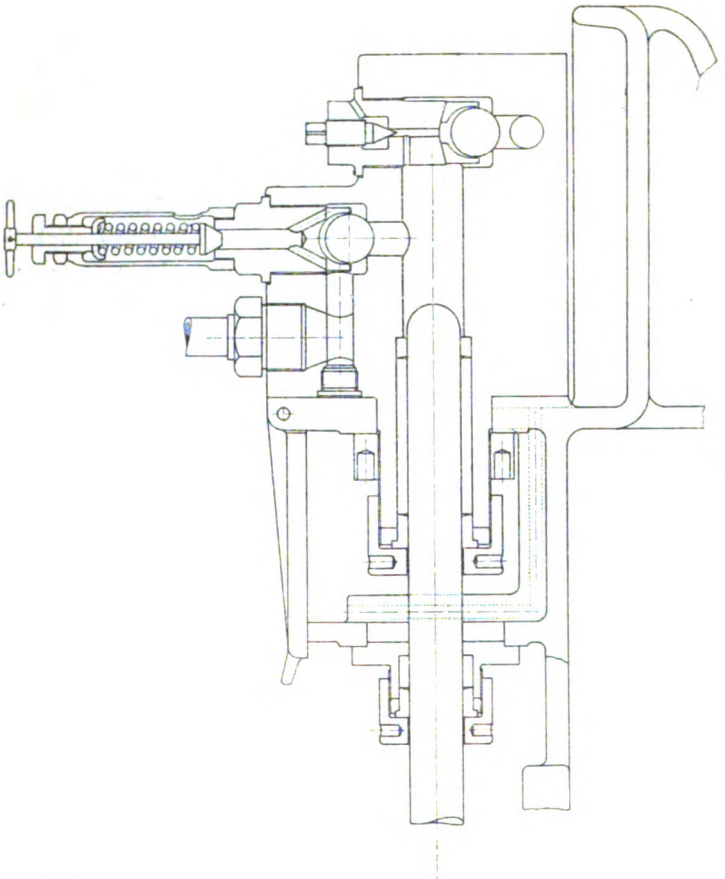

Fig. 7b.

The special construction of the cylinder liner with a loose extension piece, which makes it possible to inspect or dismantle the piston from below, obviated the necessity of having a loose cylinder head, and resulted in the cylinder construc-

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tion which is now typical of the Werkspoor engine. The top part of the cylinder liner is either cast in one or it may be bolted on to the cylinder head. The construction of this head, the result of many years' experience and careful elimination of errors, makes it a very safe design. It is well cooled, and is at the same time an extremely accessible casting, as will be seen from Fig. 8. In the first covers of this type, the fuel valve was placed between the inlet and the exhaust valves. As the provision for cooling the metal between the fuel valve and the exhaust valve was inadequate, frequent fractures of the metal between these two valves occurred, and it was then decided, about 12 years ago, to place the fuel valve slightly out of the centre. This alteration resulted in a more symmetrical arrangement of the valves, Fig. 9, and accidents of the nature described above have never happened since.

A most important detail of the large marine engine is the cooling of the piston, and the reliable construction of the telescopic pipes which lead the cooling medium to and from the piston. In the original design, ordinary stuffing-boxes were employed, but they gave a lot of trouble, and very frequently the pipes broke off at the base in consequence of bad alignment. It was then decided to use open pipes, three in number, one sliding within the other, with considerable clearance between them, Fig. 10. The innermost pipe and the outside one were fixed to the framing, and the intermediate pipe to the piston. The first pipe had a nozzle with a small hole, and the water was injected into the piston in a fine spray. The function of the outside pipe was to collect the leakage, and it was afterwards fitted with a stuffing-box provided with floating scraper rings in order to deflect the water from the moving pipe, as this water was often thrown off against the cylinder walls, spoiling the lubrication and causing the piston to blow. This final arrangement is giving complete satisfaction, and has proved to be entirely reliable. The heated water and the leakage water are separately con-

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Fig. 8.

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veyed to an open funnel, which enables the engineer to make sure that everything is in order.

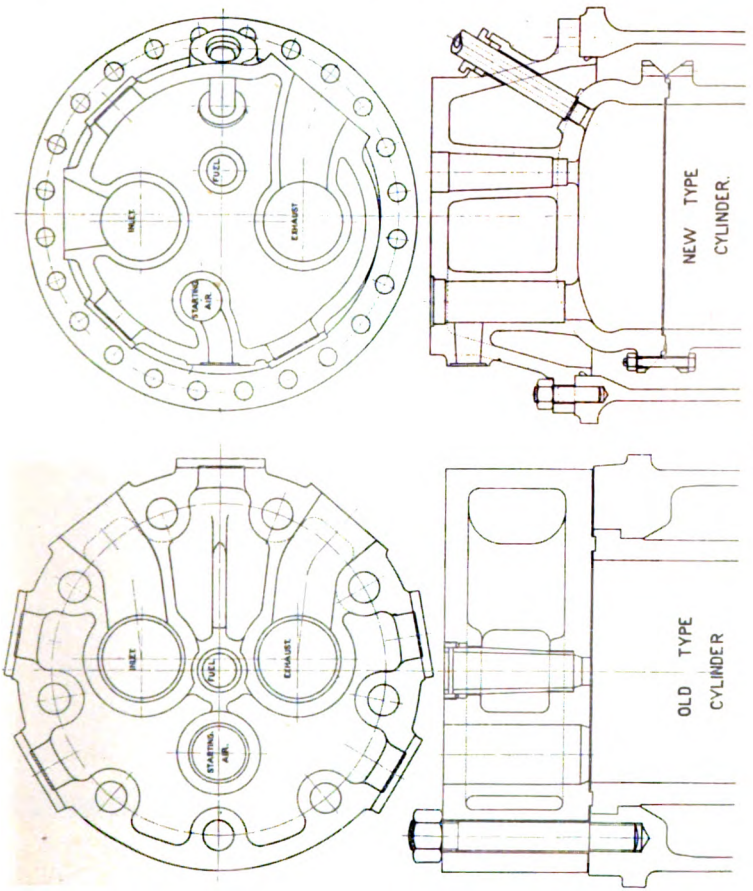

Fig. 9.

The reversing system used on the early type of engine was very much the same as that fitted to the "Vulcanus," the only difference being that the rocking bracket with the bearings for the ahead and astern camshaft was superseded by straight guides, Fig. 11, on which the camshafts were

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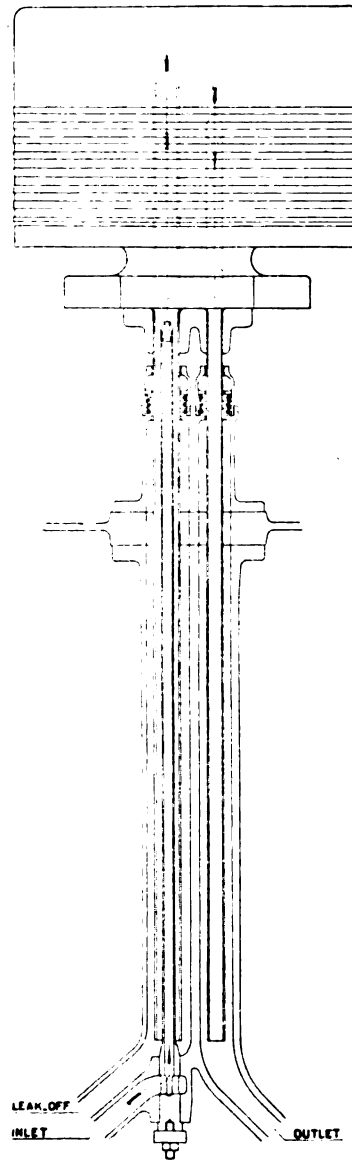

Fig. 10.

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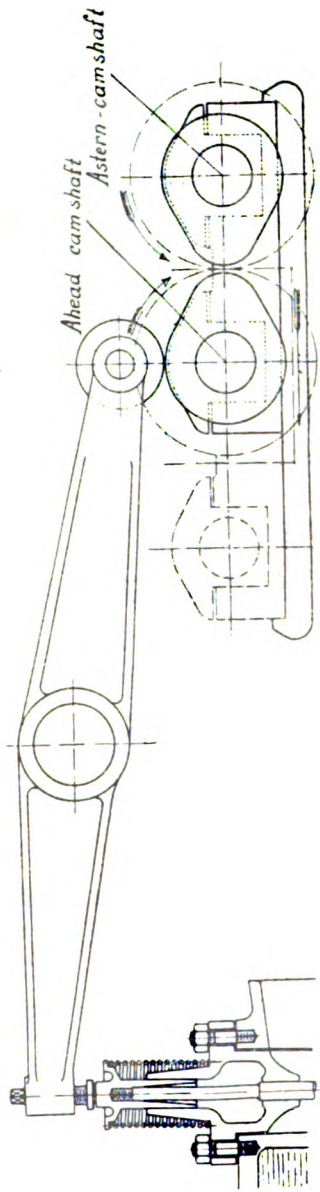

Fig. 11.

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moved sideways in order to bring either the ahead or the astern cams under the rollers of the levers. When the engine was working both shafts were revolving, one of them, of course, idly.

The driving gear for the camshaft is of a somewhat unusual nature, and it deserves special attention. A spur-gear wheel on the camshaft drives a shaft which runs at half the engine speed. This shaft is furnished with four cranks, and is connected by four coupling rods to a similar crankshaft coupled to the camshaft. These rods are only built to withstand tension, and the bottom brasses of the top bearings are left out. In order to keep them as light and as stiff as possible, they are made from steel tubing, which is split up in the sides and opened out in the middle by a number of stay-bolts, Fig. 12.

Here again a constructional detail well known to every engineer was used, namely, that the wear and tear can be easily taken out by adjusting the brasses. This construction proved so reliable and satisfactory that it is still being used practically unaltered in the engines of to-day. The reversing mechanism itself, however, has now been superseded by a lighter and simpler construction, which represents perhaps the most simple system of reversing in use. The leading types of reversing mechanisms can be classified under the following four heads:—

1. Ahead and astern cams on two different shafts which are moved sideways under the rollers (Werkspoor old system).
2. Ahead and astern cams on one shaft which is moved lengthwise while the rollers are being lifted off the cams (Burmeister & Wain).
3. Valve levers having two rollers which can be brought alternatively into contact with the ahead or astern cam, a stationary camshaft being employed (Sulzer).

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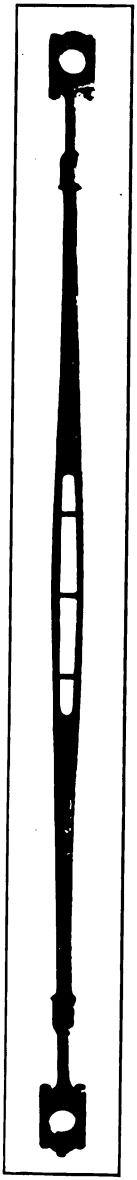

Fig. 12.

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4. Valve levers having only one roller which can be brought into contact with the cams on a stationary camshaft by moving the valve levers (Werkspoor new system), Fig. 13.

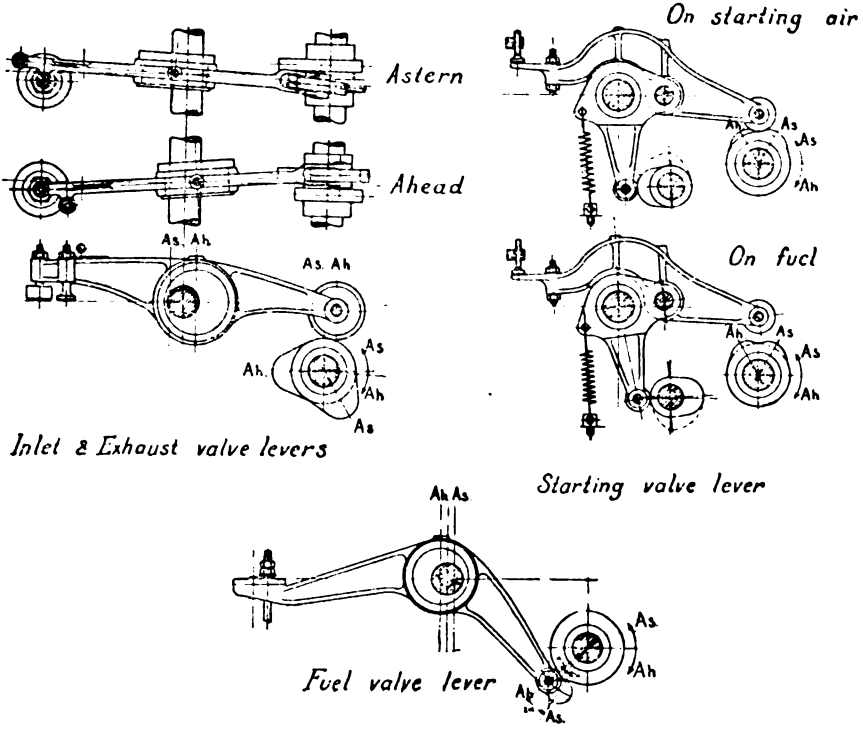

Fig. 13.

The latest system now adopted by Werkspoor may claim to be the simplest because there is only one roller to each lever, and only one camshaft which does not require to slide longitudinally. The levers are mounted on eccentrics on the reversing shaft, which can be rotated through 180 degrees. In mid-position all the rollers are clear of the cams. The eccentrics are keyed on the reversing shaft at a certain angle, so that the lever is slightly askew, although the axis about

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which it turns is horizontal both in the ahead and astern positions. When the reversing shaft is turned through 180 degrees, the angle of the eccentric and of the lever is reversed; incidentally the roller is lifted up from the ahead cam, and is brought down on the astern cam. The axis of the roller, which is parallel to the camshaft in the ahead position, is at a slight angle to it in the astern position. The astern cams are, therefore, rounded off, and in this position there is only line contact between the cam and the roller, but as the astern running time is only a fraction of the whole time the engine is working, this is a detail of little importance. The other end of the lever is provided with two tappets, one for ahead and one for astern working, and this end of the lever is held down by a cross bar while reversing. For reversing, all that is necessary is to turn the reversing shaft, which carries the eccentrics on which the levers are mounted, through an angle of 180 degrees. For this purpose, an air cylinder with an oil dashpot is provided with a rack engaging teeth cut in the reversing shaft.

The reversing of the fuel lever is carried out on a different system. It is also mounted on an eccentric, but this eccentric is straight, and the eccentricity is so chosen that the same fuel cam can serve for both ahead and astern working.

To bring the starting levers in and out of action, a third shaft is provided which is moved by hand in smaller engines, and by an air servo-motor in the case of larger ones.

Although the type of engine with steel columns and diagonal stays possessed several advantages, such as light weight and accessibility, it had some drawbacks which caused a return to the original cast-iron frame construction employed on the "Vulcanus" engine.

When forced lubrication was introduced, the crank-casing had to be entirely enclosed, the steel splash plates being quite insufficient for the purpose. Even an entirely enclosed housing of steel plates could not be kept sufficiently oil-tight

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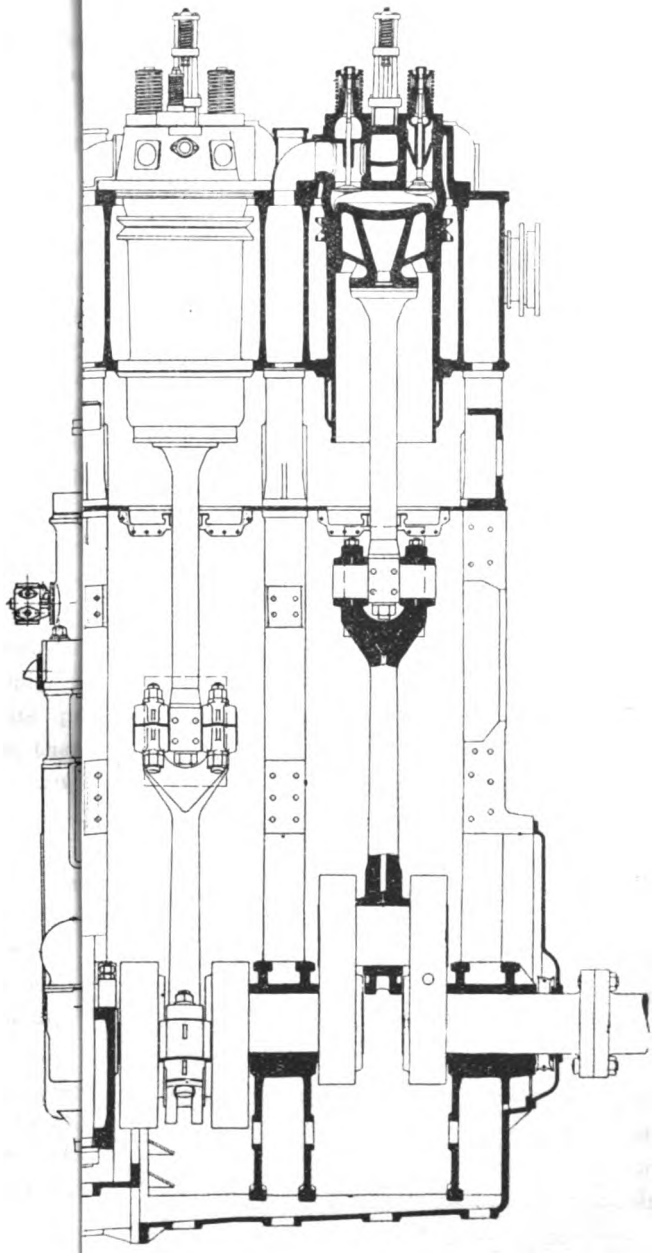

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to keep the engine-room clean, and the lubricating-oil consumption as low as possible. The engine now being built as a standard has cast-iron frames between the bedplate and the cylinder beam, the through bolts being retained, Figs. 14a and 14b.

These frames are placed on both sides of the main bearings, the guide plates being bolted on to them. Over the top of the lower columns a heavy steel plate is fitted which ties them all together, and, incidentally, shuts off the crank-casing so efficiently that no water can enter it. Not a single sea-water connection is made inside the casing, thus no water leakage can contaminate the lubricating oil. The cylinder liner is bolted to the head instead of being cast in one with it, as the head will last longer than the liner, and a liner can now be renewed without having to fit a new head. Also the head and the liner can be made from the material best suited for each, whereas in the case of the head and liner being made in one, some compromise had to be made.

Otherwise the Werkspoor engine of to-day remains essentially as it was, having developed in a natural way from its predecessors. In technical matters, even as in Nature, there is a law of the "survival of the fittest." What is best can often only be determined after years of running experience; therefore, development is naturally slow. It is true that in Diesel-engine construction there is great scope for invention, but every new idea or modified detail may be a source of fresh trouble, perhaps more so in this branch of engineering than in any other. No better principles can be adopted than "leave well alone," go step by step, and keep your feet to the ground, that is, the solid ground of experience.

Having dealt in the foregoing with the past and the present, I now direct attention to the future. To Werkspoor the future concerns the double-acting engine, and at present more particularly, as all their experience lies in this region, the

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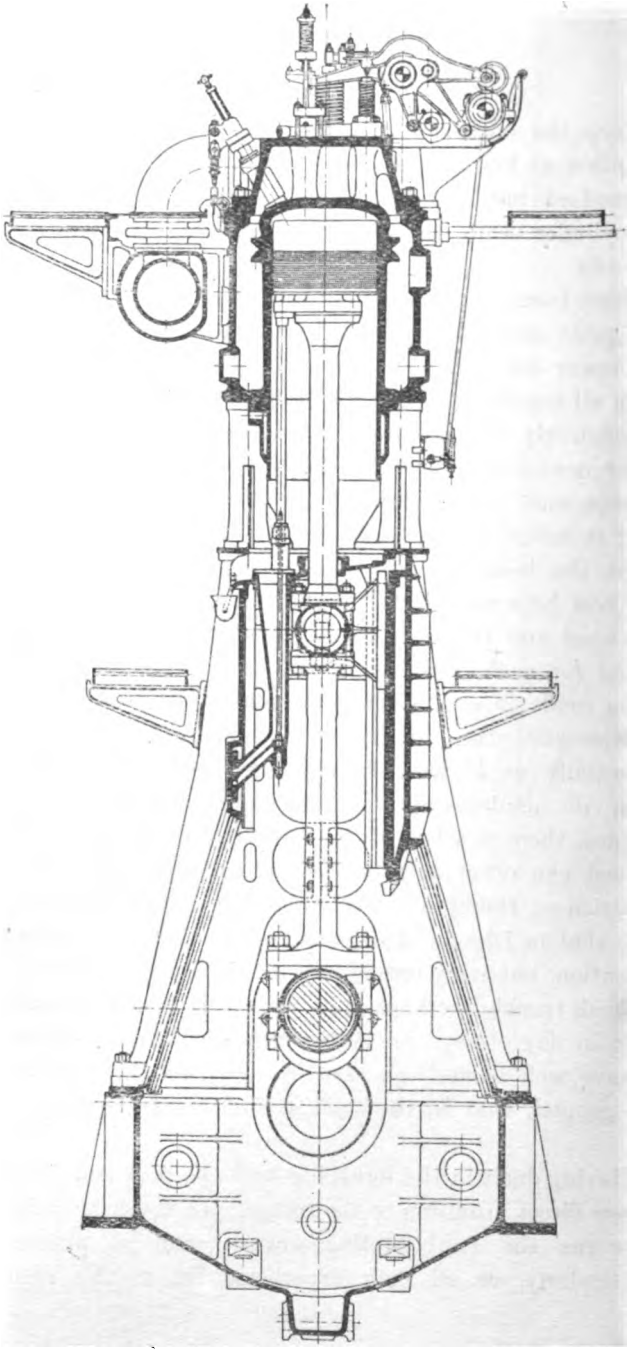

Fig. 14b.

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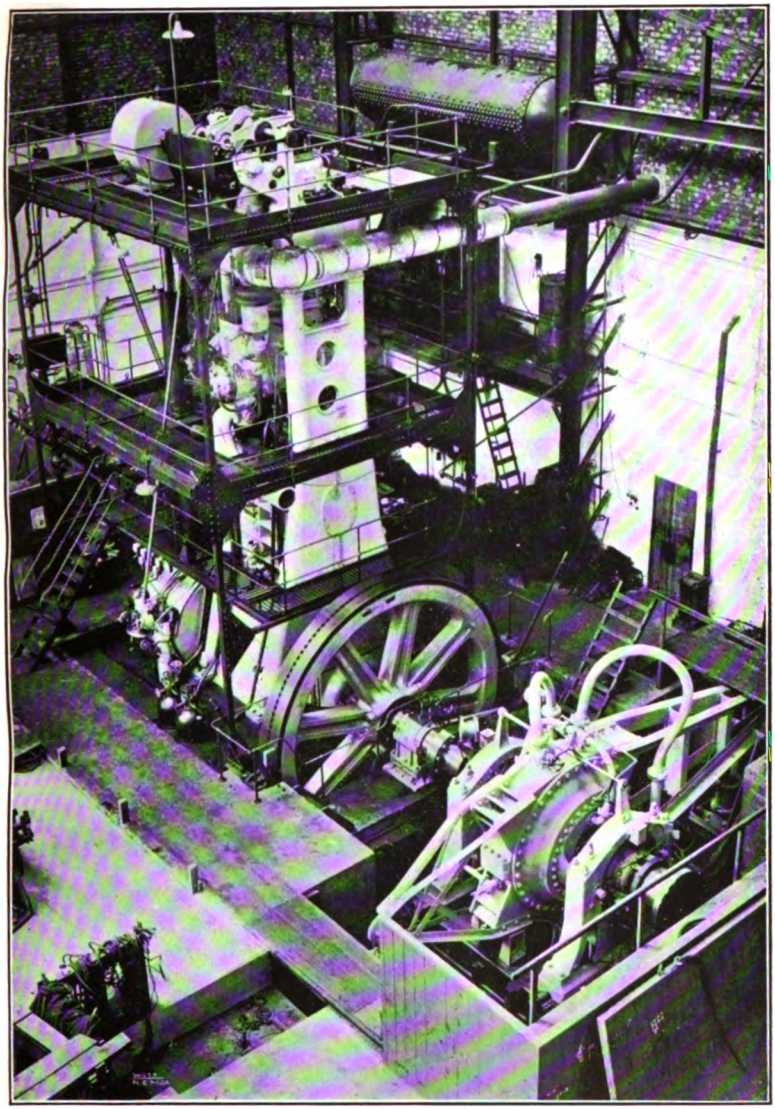

Fig. 15.

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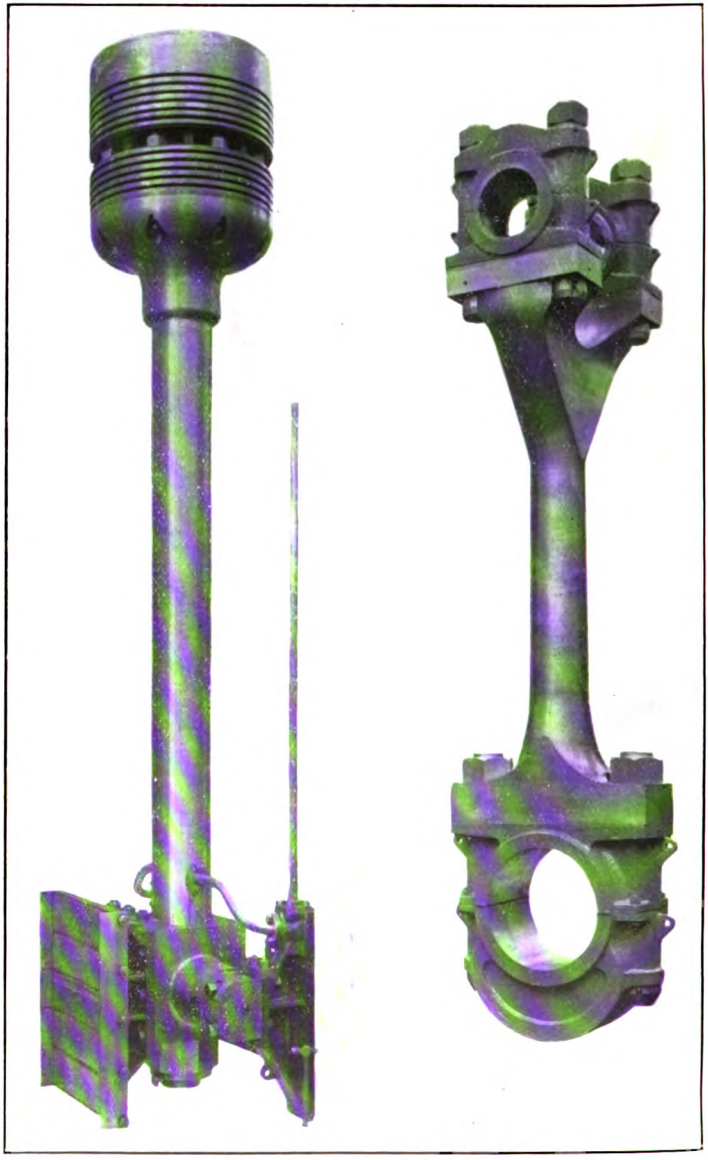

Fig. 16.

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four-cycle double-acting engine. I had the honour of reading a paper on this subject together with my friend and collaborator, Mr. Harry Hunter, before the Institution of Naval Architects in the summer of 1924, a report of which appeared in several technical papers, and I may assume that the principle of the Werkspoor double-acting engine is known to the majority of those interested in Diesel-engine work. In that paper I gave a description of the large experimental engine, which was built jointly with one of our licensees in England, the North-Eastern Marine Engineering Co., of Wallsend-on-Tyne, and which is installed in that company's works, Fig. 15. There are, however, a few points in the design of this engine which I wish to emphasise, as they appear to me to be more or less fundamental to the construction of double-acting engines.

One of the principal features of the Werkspoor single-acting engine is the piston dismounting device, which enables the engineer to inspect and overhaul the pistons in a couple of hours, and to do this without much trouble. In a single-acting engine, the cylinder being open at the bottom, the pistons can be examined very easily, and the necessity of closer inspection or overhaul can be easily judged. This is not so in a double-acting engine, and it has been deemed essential to provide means not only for judging the working of the pistons while the engine is running, but also for inspecting them without having to dismantle the important parts of the engine, which are better kept in place. This applies, in the first place, to the connection of the piston rod and the crosshead, which is naturally far more important in a double-acting engine than in a single-acting one. The double-acting engines, for example, which are now being built for Messrs. Alfred Holt & Co. of Liverpool, and also for the Anglo-Saxon Petroleum Co. of London, have a 7-inch nut on the piston rod where the latter penetrates the crosshead, Fig. 16. This connection can best be made, indeed it might almost be said that it can only be made, outside the

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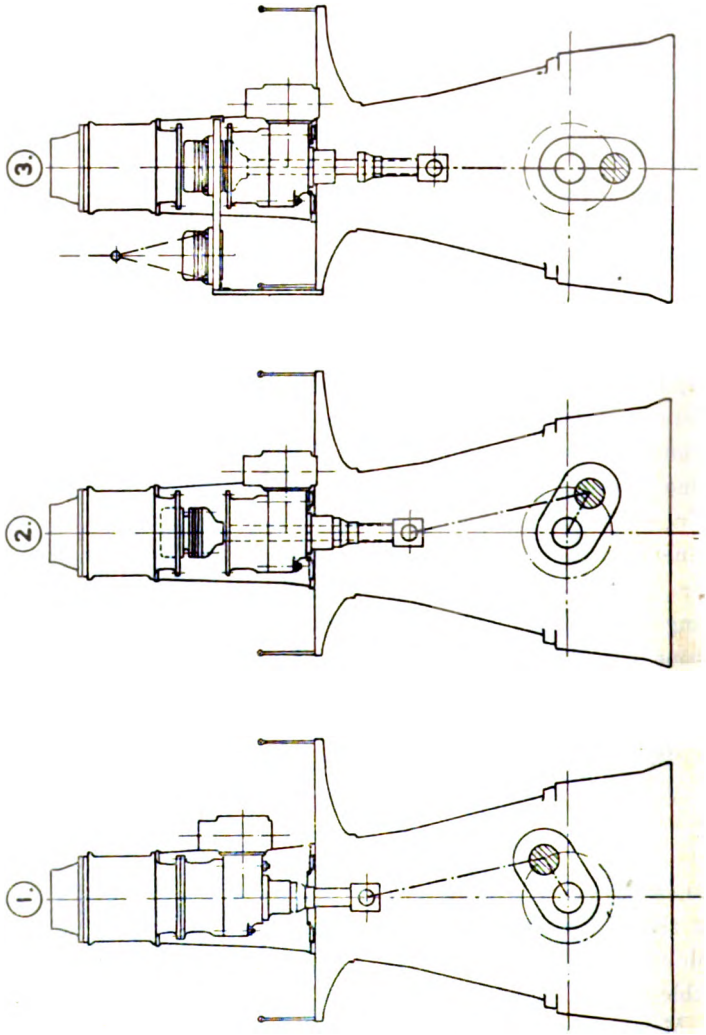

Fig. 17.

engine. To bring home properly a 7-inch nut inside the crank-casing is practically impossible; the only way, therefore, to have an accessible piston is to construct the engine in such

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a manner that the piston can be laid bare without breaking this connection. This is impossible if the piston is to be removed from the cylinder at the top, after taking off the cylinder head, as this procedure necessarily entails taking the piston rod out of the crosshead. By lowering, however, the bottom part of the cylinder in its entirety, the piston can be uncovered without breaking any connection in the moving parts, Fig. 17. After a few pipe connections and part of the valve gear have been disconnected, and the bolts have been taken out of the flange connection of the bottom cylinder and the cylinder beam, the whole of the bottom cylinder can be lowered in a very short time by means of the turning engine, after putting a distance piece between the stuffing-box and the top of the crosshead. No lifting tackle of any description is necessary, which means a great simplification, considering that the weight of the piston and the piston rod of one of the above-named engines, with 820 mm. (32¼ inches) bore and 1,500 mm. (59 inches) stroke, is over four tons.

To enable the bottom part of the cylinder to be lowered, the liner must be made in two parts, leaving a circular gap in the middle. This gap is so dimensioned that it practically closes up when the engine is warm, and it causes no trouble whatever. That this is so, also in the long run, is sufficiently proved by the Werkspoor single-acting engines, which have, as described above, a detachable extension for the purpose of piston dismantling.

It will be noticed from the cross-section of the double-acting engine, Fig. 18, that it resembles very closely the single-acting engine, with the one difference that the bottom has been closed up and provided with a separate combustion chamber, quite outside the circumference of the cylinder, in which all the necessary valves are arranged. The exhaust valve and air-inlet valves are placed vertically on the same centre line, the former being on the top, so that it can be easily withdrawn for inspection, and also in order to get a simple

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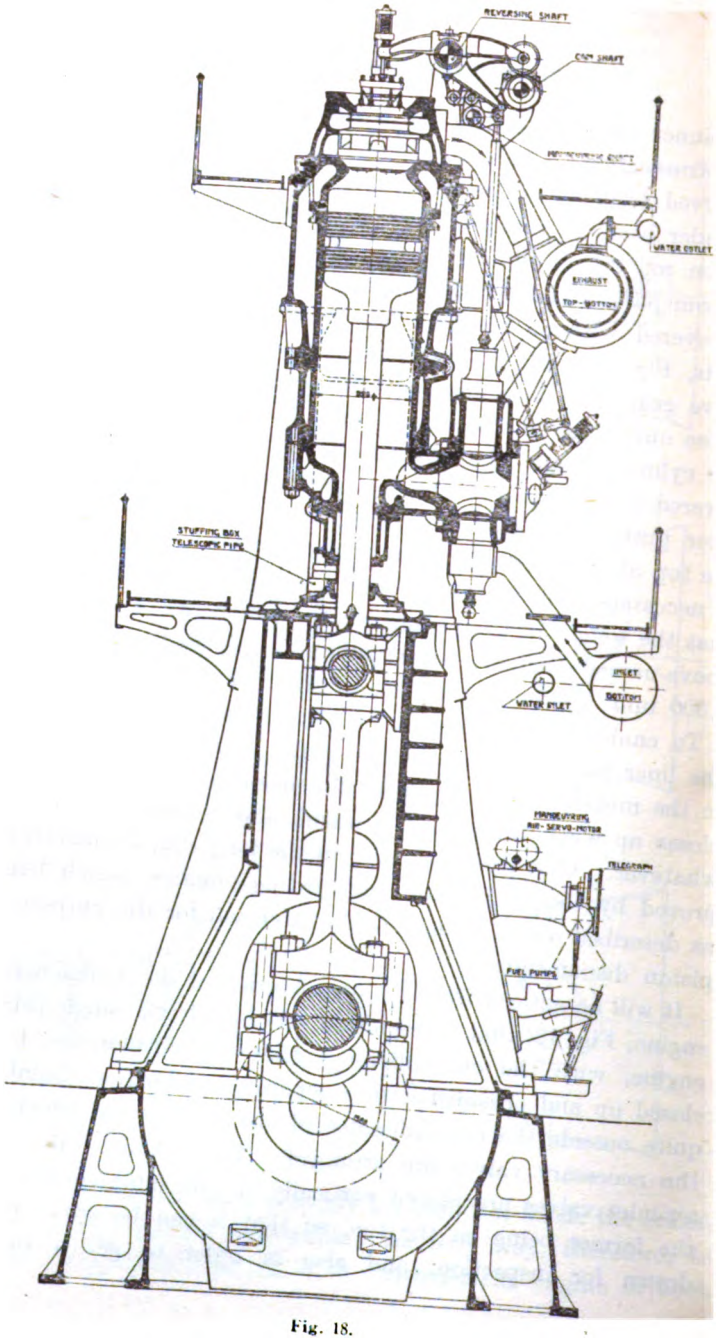

Fig. 18.

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connection to the exhaust pipe, which serves both for the top and for the bottom cylinders. The clearance between the piston and the bottom cover is made as small as permissible; the air in the bottom cylinder is, therefore, compressed almost entirely in the combustion chamber, which is only connected to the cylinder itself by a comparatively narrow throat. The fuel valve is placed in the cover at an angle of 45 degrees, pointing downward; it injects the oil horizontally in the centre line of the combustion chamber. This position of the fuel needle-valve obviates all difficulties with pulverisation which are so frequently encountered with inverted and even with horizontal fuel valves.

The size of the combustion chamber is more or less determined by the size and the arrangement of the valves, which require a certain definite diameter, and the final compression pressure comes out lower in the bottom compression space than at the top. This may be considered a disadvantage from the thermo-dynamical point of view, but it is decidedly an advantage where the reliable working of the bottom cylinder is concerned, as also from some other points of view, for which I beg to refer to the paper previously mentioned. In the engines now being built, the compression pressure in the bottom space is about 300 lbs. per square inch; the scantlings of the bottom, however, are made to withstand a maximum pressure of 500 lbs. per square inch, and the time of fuel injection is adjusted to give a card of the shape illustrated in Fig. 19, which is very much like a gas-engine diagram. After the maximum pressure is reached, the expansion follows almost immediately; the combustion takes place practically entirely while the piston is passing over its bottom dead centre.

Particular care has been taken to protect the stuffing-box against high pressure, by increasing the diameter of the top part of the piston rod which enters with a little clearance into a chamber in the bottom cover, forming a kind of differential

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piston in the cylinder, see Fig. 18. The part with the larger diameter leaves the chamber at about eight per cent. of the stroke when the combustion is well over, and when the pressure in the cylinder has fallen considerably. The wire-drawing effect in the clearance has a cooling effect on the gases, and the pressure in the chamber is considerably lower than in the cylinder itself. All this co-operates in keeping the piston rod itself remarkably cool without having to

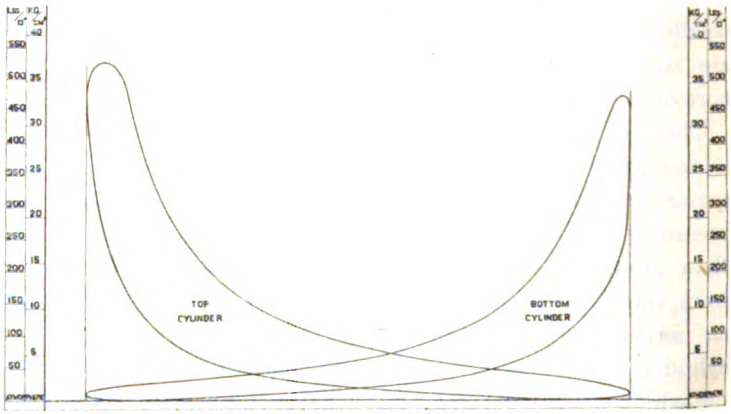

Fig. 19.

employ a means for cooling it. It is indeed cooler than anyone, who has not felt it while the engine is working at full power, would believe. Incidentally, I may mention that the piston rod is provided with no other means of cooling than the piston-cooling water passing through a 2½-inch hole in the centre of the piston rod.

This, in addition to the fact that the mean indicated pressure in the bottom cylinder is about from two-thirds to three-quarters of that allowed in the top cylinder, tends to keep the stuffing-box in good condition. The experimental engine has now made very nearly 20 million revolutions since it was first started, and there never has been any trouble experienced

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with the stuffing-boxes, in the construction of which nothing new was attempted. They are simply of a type which had proved to be successful in double-acting gas-engine practice, where the conditions are almost identical to those in the double-acting Diesel engine.

The valve gear of the double-acting engine is very similar in design to that used on the single-acting engine. The camshaft, which is driven in the same way as previously described, is placed at the level of the top cylinder cover, and it carries the cams for the valves in both the top and the bottom cylinder covers, the latter being driven by means of push rods and intermediate rocking levers. For the fuel valve, a compensating gear had to be devised in order to deal with the extension and deformation caused by heat. The reversing system used on the single-acting engine, however, was not suitable for the double-acting engine, and it was replaced by a system with a sliding camshaft.

As already mentioned, in co-operation with our British licensees, 12 engines of the double-acting type are under construction for the Anglo-Saxon Petroleum Co. of London. These are of the size previously referred to, and, on the whole, are based on the design of the single-cylinder experimental engine which proved so entirely successful during a non-stop run of more than 20 days in May of last year. They possess, however, some novel features which were devised in collaboration with Mr. C. Zulver, the marine superintendent of the Anglo-Saxon Petroleum Co., and merit description.

There are few ships that have as little time for overhaul, inspection, or repair as tankers. The average actual working time of the engines in a tanker is about 6,500 hours per annum, and even in port, repair work on board is often prohibited, owing to the danger caused by open fires when handling low-flash oil cargoes. Taking into consideration the exceptionally large size of the cylinders, the design of the cylinder head was simplified as much as possible. It is of

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quite a symmetrical shape, and with only one opening in the middle for accommodating the necessary valves. This opening had to be, of course, of the smallest possible diameter, Fig. 20. As, in an ordinary cylinder cover of a four-cycle engine, there is hardly room enough for the four valves, namely, the inlet, the exhaust, the fuel, and the starting valve, this necessarily led to combining the inlet and the exhaust valves, and in order also to avoid the use of a large-sized mushroom-type of valve, a valve casing with the fuel valve in the centre and six small valves surrounding it was developed. The increased number of valves would seem at first to add complication, but everyone knows that small valves, especially if cooled and run at a very low speed as these are, never give any trouble. This valve casing, Fig. 21, is comparatively light, has a seat diameter of only 60 per cent. of the cylinder bore, and can be very easily removed and replaced if necessary. A spare is carried for each valve casing, just as is usual for the ordinary exhaust-valve cages. From each valve a separate conduit leads to a cone-shaped seat on the valve casing. The latter is surrounded by an oscillating sleeve, in which 12 apertures are made, six leading horizontally to the exhaust belt, and the other six vertically to the inlet belt, Fig. 22. The sleeve is moved by an eccentric on the camshaft, and this motion brings alternatively the exhaust belt and the inlet belt into communication with the ports in the valve cage. A suitable labyrinth packing is provided between the two belts. The valve cage is, of course, cooled, but cooling is not provided in the sleeve.

As this was a radical departure from standard practice, it was deemed necessary to try the system out before applying it to a large number of cylinders. Accordingly a cylinder head of the new design was fitted to the experimental engine, which was run for a considerable time with the new device under conditions approaching sea-going conditions as nearly as possible. It ran consecutively for 82 days, perhaps the longest

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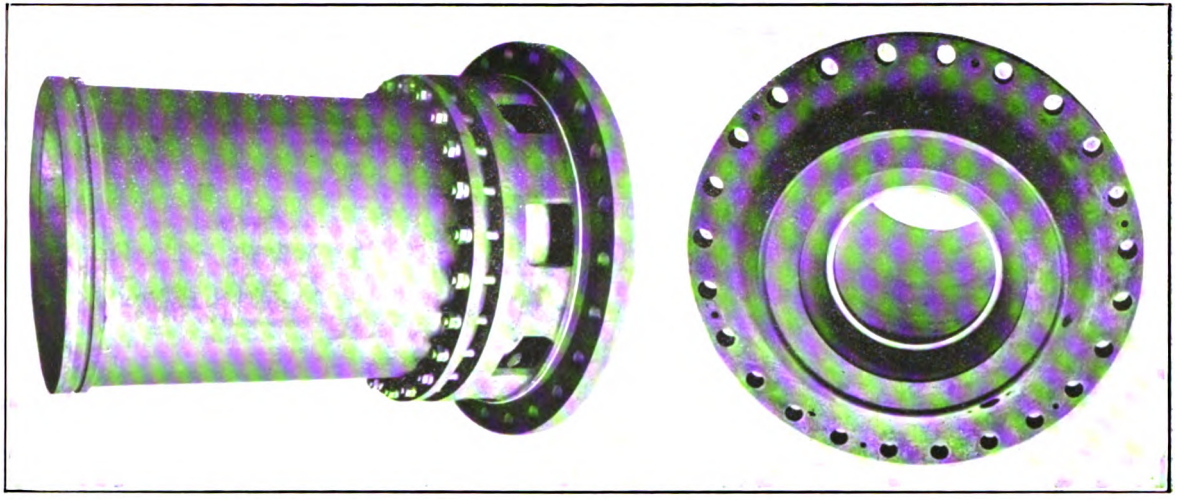

Fig. 20.

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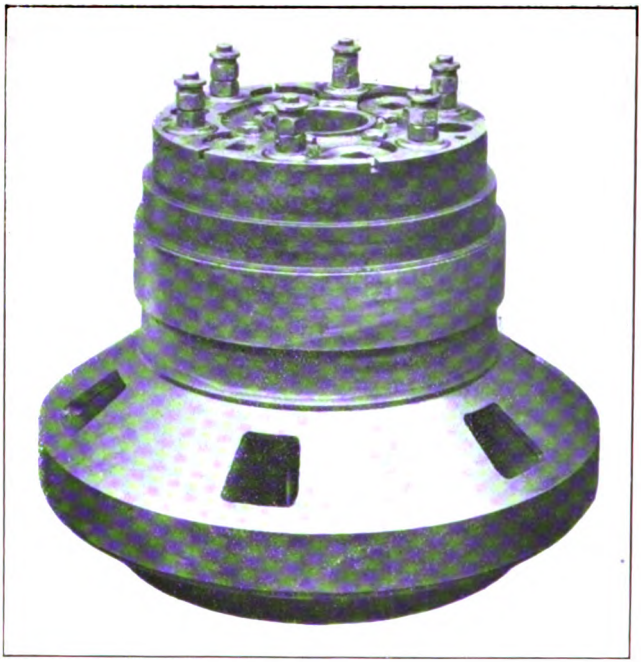

Fig. 21.

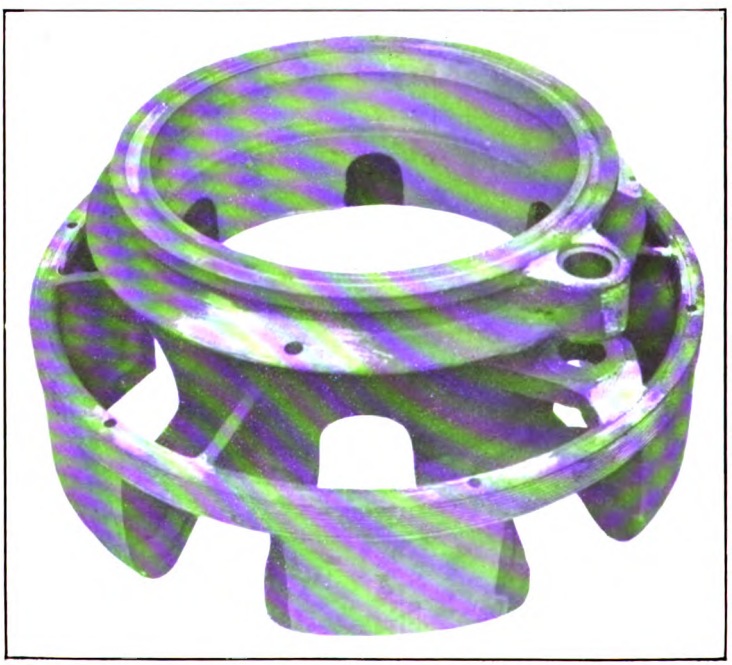

Fig. 22.

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trial ever made with an experimental engine, and during that time the whole of the gear gave entire satisfaction. It was assumed that the engine was propelling a ship, and the daily distance, calculated from the number of revolutions, was marked on a chart. The total distance amounted to about 26,000 miles, representing a complete tour round the globe, the assumed route being from London to Curaçao, Panama Canal, Honolulu, Yokohama, Shanghai, Singapore, Colombo, Suez Canal, and back to London.

On opening up the engine after this long run, both the sleeve and the seat were found in excellent condition, and there was no abnormal wear and tear. When the eccentric rod was uncoupled directly after the engine was stopped, the sleeve could be easily moved by hand.

The fact must not be overlooked that all the important parts of an engine of these dimensions and power are fairly heavy, and in carrying out any repair it very soon becomes necessary to call in shore aid and the assistance of cranes, help which, as a rule, is not available in the oil bunkering ports, and to obtain which the ship might have to go far out of its course.

As mentioned before, the compression pressure on the bottom side of the piston is only 300 lbs. per square inch, and with this pressure self-ignition cannot be expected. When the engine is running, however, and only the top cylinders are firing, conditions are entirely changed, and only a little heating up of the bottom cylinders is sufficient to raise the final compression temperature to that point where self-ignition will easily take place. The method used for heating up the bottom cylinders on the engines which are being built for the Anglo-Saxon Petroleum Co. is quite simple, Fig. 23. A valve is placed between the exhaust pipe and the inlet-air pipe of the bottom cylinders. Before putting the bottom cylinder on fuel this valve is opened, and a butterfly valve in the inlet pipe is closed. Consequently the bottom cylinders,

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instead of getting fresh air, are filled with exhaust gases expelled from the top cylinders during the suction stroke. The gases are compressed in the bottom cylinder, and exhausted again in the ordinary way into the exhaust manifold. After a few minutes, the temperature in the cylinder is raised sufficiently to put the fuel on to the bottom side also. The

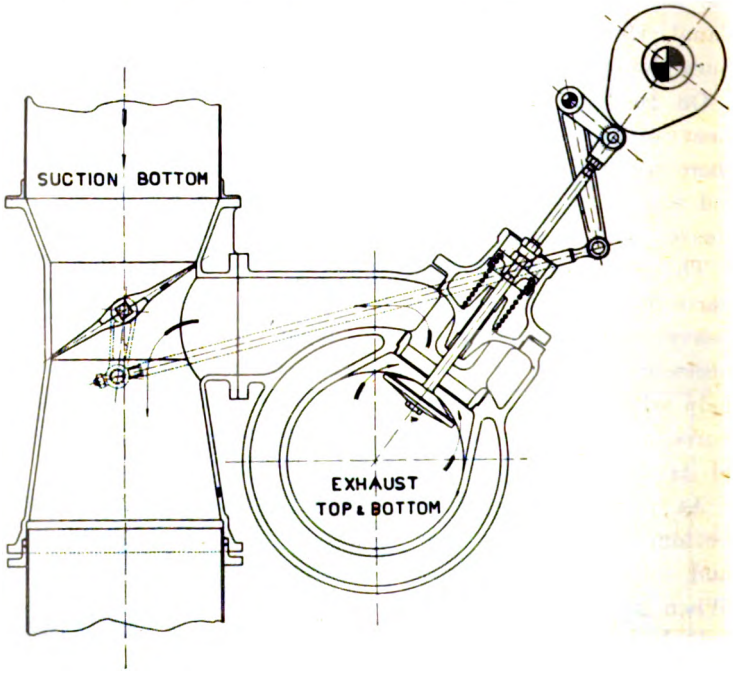

Fig. 23.

manœuvring of these valves is entirely automatic, as they are worked from the manœuvring shaft, which is moved to the required position by means of an air servo-motor. There are six positions of this shaft marked on a dial placed at the control platform:—First, stop; second, six cylinders starting air; third, six top cylinders fuel, three bottom cylinders starting air; fourth, six top cylinders fuel; fifth, six top

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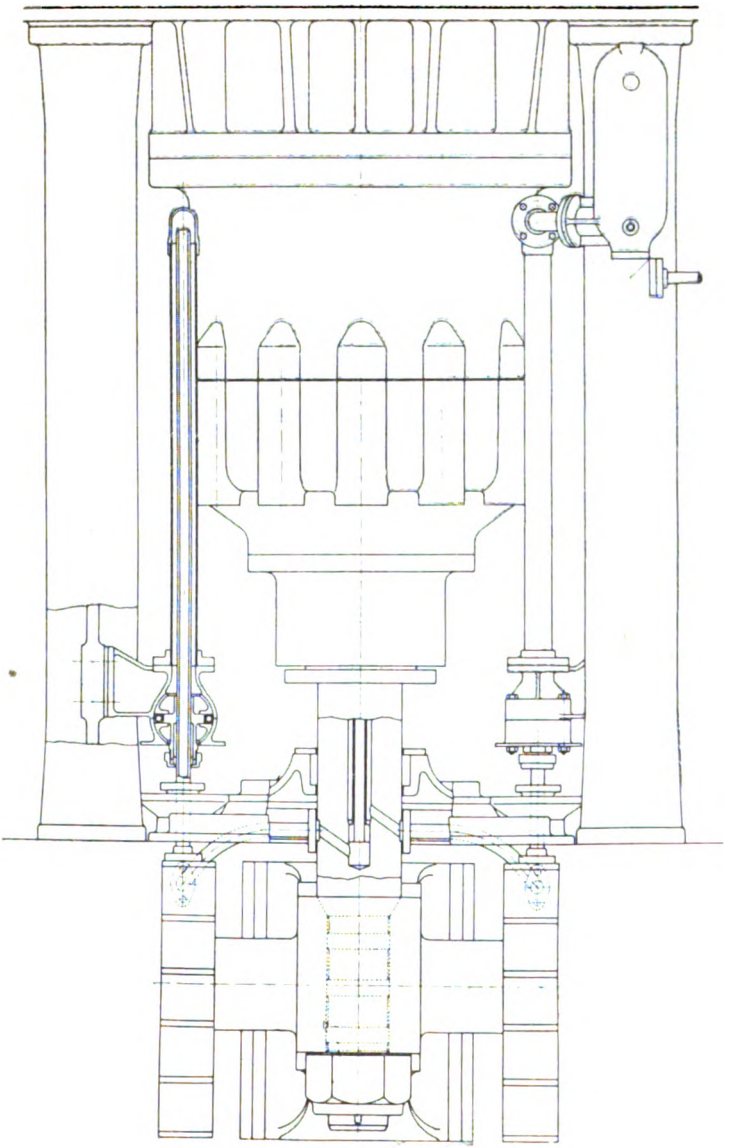

Fig. 24

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cylinders fuel, preheating bottom; and sixth, six cylinders fuel top and bottom.

When the manœuvring shaft is in the positions one to five, the bottom fuel-lever is lifted off the cam, and the suction valves of the bottom fuel pumps are lifted off their seats, thus putting these pumps out of action.

The type of fuel pump used on the single-acting engines, as described in the foregoing, is not suitable for the double-acting engine. It is necessary to use a separate pump for each cylinder. The fuel pumps, six in number, are double-acting, and are driven by eccentrics on the half-speed shaft. An Aspinall governor is provided to lift the suction valves when the engine speed exceeds a certain limit.

As the piston-cooling water (fresh water) must pass through the piston rod, a closed system of piston cooling had to be introduced instead of the open system used on the single-acting engine. The water connections inside the crank-casing, which are, of course, inevitable, are reduced to the smallest possible number, and the stuffing-boxes are fitted in accessible positions on the crank-case top, care being taken that no leakage-water can enter into the crank-casing. The stuffing-boxes are of the floating type, and do not exert any forces on the telescopic pipes which might cause fracture of the pipes, Fig. 24. The hot water is led to a funnel, and hence to a compartment in the double-bottom of the ship. A piston-cooling water pump forces it through a cooler and back to the pistons.

It was previously mentioned that means are provided for judging the behaviour of the pistons while the engine is running. It is indeed a disadvantage of the double-acting engine that, the cylinder being closed at the bottom end, it is impossible to watch the piston in the same way as in the single-acting engine. In the bottom cylinder liner is a small opening closed by a spring-loaded valve, which is worked by a special cam on the camshaft and connected to a gauge. The valve is opened at the end of the top combustion

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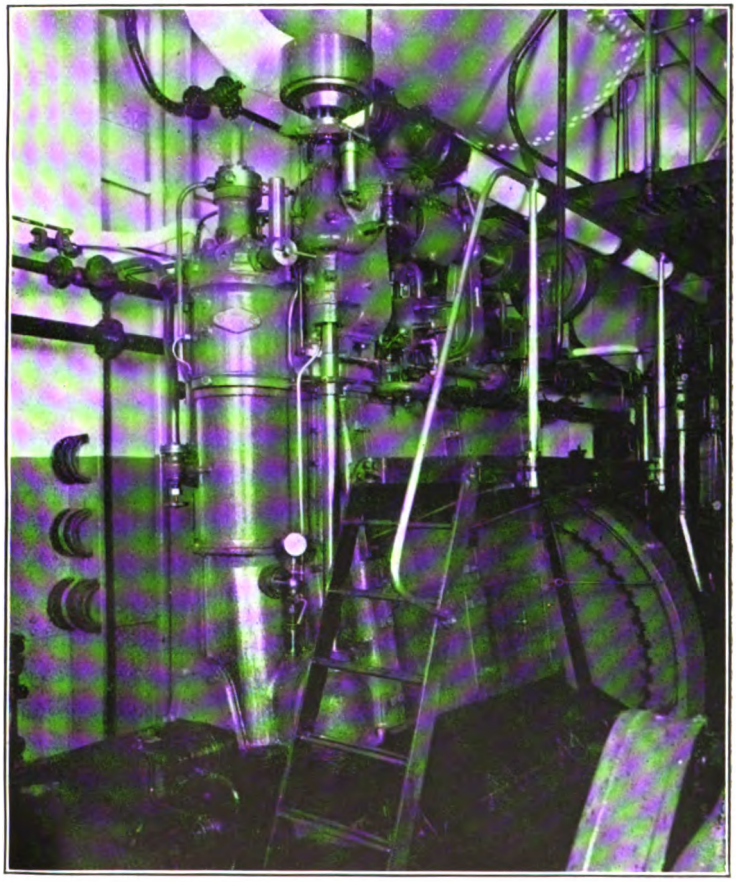

Fig. 25.

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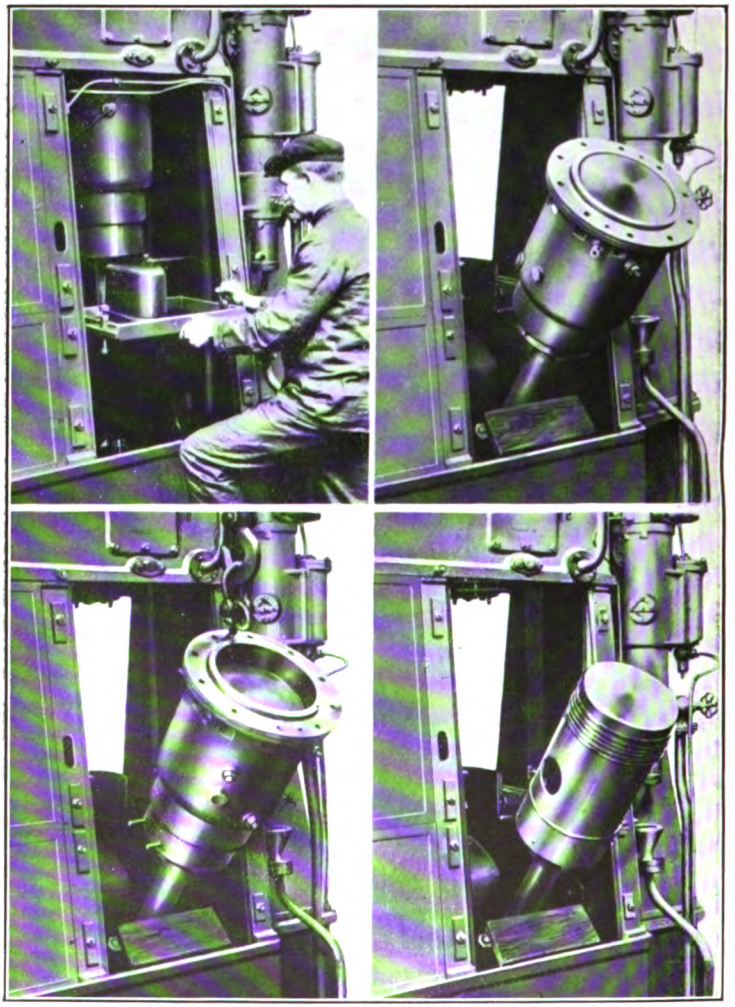

Fig. 26.

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stroke, and remains open during the time that the gap between the two groups of piston rings passes the opening. Thus the gauge is made to register the pressure in this gap. Leaking rings will cause the pressure in the gap to rise, which will show on the gauge. This simple device enables the engineer to look, as it were, into the cylinder while the engine is running. It has proved to be very reliable and of great value, as even a tendency to leak can be detected. Prevention being better than cure, measures can then be taken to prevent the trouble becoming more serious.

Having described in the foregoing some of the special devices and constructions embodied in the Werkspoor double-acting engine which contribute to make it as reliable and accessible as the single-acting engine, I now wish to say a few words about the auxiliary engines which are of such great importance in marine Diesel installations. A type of auxiliary engine has been developed which is essentially a marine engine, and requires very little attention from the engineers, Fig. 25. High speeds are not favoured with this type of engine, and as a rule it is not run at more than 250 revolutions per minute. The trunk piston can be dismounted from below in a similar way as described for the single-acting cross-head engines, Fig. 26. The framing consists of cast-iron columns carrying a cylinder beam, into which the cylinders, cast in one with the heads, are inserted. Through-bolts pass through the beam and the columns, tying them to a rigid bedplate. The steel doors between the columns can be easily removed, and give free access to the bearings and the moving parts, and also to the detachable cylinder extension, which has to be lowered in order to uncover the piston for inspection or overhaul. An important advantage derived from this construction is that no head room for dismounting the pistons is required on board ship. The engines may be placed under a deck, or eventually under a starting-air reservoir, with just enough room for a man to stand on the platform.

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Werkspoor have built and are building a number of installations in which the main engine is entirely self-contained, all the necessary pumps being driven direct from the engine itself. This procedure tends, of course, to simplify the engine-room arrangement, especially when the exhaust gases are being used for heating boilers, which as a rule raise sufficient steam for running the steering gear, the steam dynamo, and at times a refrigerating plant. But in other ships a certain number of auxiliary Diesel engines is installed, one or more of which must be running continuously to generate the current for the electrically-driven pumps. It is obvious that the construction of the auxiliary engines should have not less attention from the designer than the main engine. This saying may seem commonplace, but it is often overlooked that not every stationary engine is suitable to be installed in a ship.

All the engines described above are four-cycle engines, which might lead to the conclusion that Werkspoor are opposed to the two-cycle system. This, however, is not the position, for Werkspoor acknowledge that this system has its advantages, and I personally think that it would be foolish to deny them. However, no formulæ, no words, be they written or spoken, can ever bring a decision in the competition between the two systems; no supreme power has decreed that the one shall live and the other die! It is only facts, experimental facts, that count; reliability, durability, first cost, cost of upkeep, economy in the long run, in one word—efficiency. Therefore, Werkspoor do not commit themselves exclusively to the one system, but are at this very moment going in for a comprehensive trial of the other, having built a large double-acting two-cycle experimental engine which will shortly be erected in the Amsterdam works. This trial and its hoped-for consequences may in the future form the subject of a third chapter to the story of the Werkspoor Diesel engine. I, therefore, do not finish my paper with the customary words, "the end," but beg leave to say—to be continued.

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Discussion.

Mr. JAMES RICHARDSON, B.Sc. (Member): There is one piece of technical activity on which I think we, as an Institution, can congratulate ourselves, and that is the quality of the papers read during the last few sessions describing some of the leading types of marine Diesel engines. In tracing the progress of the development of the Diesel engine, the avoidance of localised and intensive heat stresses has been a leading motif towards many of the important changes, more of methods and detail than of principle.

The normal four-stroke cycle engine must have in the cylinder head one or more inlet valves to permit of the drawing in of air by the piston on its downward stroke to support combustion, and of one or more exhaust valves to allow of the escape of the products of combustion pushed out by the piston on its upward stroke. These valves must be of a certain minimum size in order to maintain a reasonable main cylinder volumetric efficiency. Any reduction in size of these valves leads to wire-drawing and to a loss of power and efficiency. The accommodation, therefore, of these necessarily large valves in the cylinder head leads to difficulties in providing sufficient water-cooling spaces around the pockets, particularly the longer the stroke of the engine, *i.e.*, the higher the stroke-bore ratio, as is the distinct tendency with marine internal-combustion engines of to-day.

Such considerations led the well-known firm of Messrs. Franco Tosi & Co., of Italy, to design and experiment ten years ago with a gear for placing the cylinder head valve-chambers alternately in communication with the admission port and the exhaust port, so that the same valves in the cylinder head controlled the admission of the inlet air and the escape of the exhaust gas from the working cylinder. This arrangement was standardised. At the present time there are working the world over and at sea a total of many thousands of cylinders of four-

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Mr. James Richardson, B.Sc.

stroke cycle internal-combustion engines in which this principle operates. I have been associated with the incorporation of this gear in the Beardmore-Tosi engines as fitted to a number of ships. The advantages by way of reducing the size of valves it is necessary to accommodate in the cylinder head, and by so doing of diminishing heat stresses, are very considerable. The strength of the cylinder head is augmented. The maintenance of the valves is reduced, and in some cases these valves have run from 40,000 to 45,000 miles without requiring regrinding.

The same reasons evidently have led the designers of the engine described to us this evening to adopt exactly the same system in connection with their double-acting engines for the top of the cylinder. If it is the best system for the top of the cylinder of double-acting engines, it is also the best for single-acting engines, and for the bottom of the cylinder of double-acting engines.

In conclusion, I should like to congratulate Mr. Lugt upon the extremely fortunate position in which he finds himself. He will shortly commence to run his third experimental large double-acting cylinder, and in that respect he must be unique among Diesel engineers of the world.

Mr. W. B. Fulton (Associate Member): I think the Institution is indebted to Mr. Lugt for coming all the way from Amsterdam to relate to us what he aptly designates the "romance" of the Werkspoor Diesel engine, and I feel sure that after hearing his story members will look forward with interest to hearing the sequel of the romance which he holds out in prospect.

My first acquaintance with the Werkspoor Diesel engine was more in the nature of tragedy than romance. It occurred some 20 years ago at a demonstration trial of one of the first Diesel engines built in Amsterdam, when I burnt my fingers trying to gauge the temperature of the cylinder jacket cooling

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Mr. W. B. Fulton.

water. Consequently I then became convinced that, in the first place, the Diesel engine was a decidedly high-temperature engine, and in the second place, that a lot of the heat developed ran to waste.

From what Mr. Lugt states, I think it will be generally conceded that the Werkspoor firm can justly claim to be pioneers in Diesel-engine construction. For instance, the method they have devised for examining and removing the piston from the side instead of, as is usual, from the top of the cylinder is a very original one, and I should think requires less dismantling of parts, and is, therefore, easier than the usual method adopted for that purpose. Again, the method of supplying fuel oil to the cylinders by means of one pump only, working in conjunction with a floating reservoir, is very clever. In this connection, Mr. Lugt says "The type of fuel pump used on the single-acting engines . . . is not suitable for the double-acting engine." Why? Is it because the injection or compression pressure is different on the top and bottom ends of the cylinder? The idea of preheating the bottom end of double-acting cylinders by means of the exhaust gases from the top end is also original, although it involves a departure from the Diesel principle as well as some loss in efficiency.

Does Mr. Lugt anticipate any trouble from the piston-rod packing if the pressure on the bottom end of the cylinder were as high as that on the top end, or is the compression pressure on the bottom end kept low principally on account of the greater clearance volume due to the separate combustion chamber fitted on the side of this space? Early in the paper Mr. Lugt says—I think for the "Juno"—that Werkspoor did away with forced lubrication and adopted an open framing. It would be interesting to know what their experience with the open machine was, as apparently a return has been made to forced lubrication.

It is interesting to hear that the Werkspoor firm are also

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Mr. W. B. Fulton.

experimenting with a two-cycle double-acting engine, because I think that, just as the demand for higher powers has compelled makers of the four-cycle engine, such as Burmeister & Wain and Werkspoor, to go in for the double-acting engine, the insistence on still higher powers will compel makers to consider the claims of the double-acting two-cycle motor. I hope that after these experiments have been carried out Mr. Lugt will again visit us for the purpose of continuing his interesting romance.

Mr. Robert Love (Member): Mr. Lugt deals with the history of the Werkspoor Diesel engine in a most interesting manner. His reference to the "Vulcanus" having been continuously engaged abroad since leaving Europe in 1911 proves that the marine Diesel engine can hold its own with the steam-engine as regards continuous service.

There are a few items mentioned in the paper on which I would ask for some enlightenment. Mr. Lugt shows a design of cylinder head with a bolted joint between the head and the liner. This joint is located in the water-jacket space, and in the case of leakage it would be a most difficult joint to remake. It is evident that the difficulty of housing the large-size exhaust valves necessary with the increased stroke-bore ratios now used, and at the same time retaining sufficient metal in the head between the fuel valve and exhaust valve openings, has forced the designer to use this type of head. From the paper on the Burmeister & Wain Diesel engine, recently read before this Institution by Mr. Blache, it would appear that the same reasons had necessitated a design of cylinder-head joint on similar lines to the above.

Regarding the ingenious fuel system which has been largely used in connection with the Werkspoor Diesel engine, it seems to be possible to flood the fuel valves during any stoppage of the main engine should the fuel control lever be left in the running position. I have no doubt that some safety

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Mr. Robert Love.

contrivance is fitted to obviate trouble such as this, and further information on this point would be appreciated.

In connection with the double-acting engine, it would be interesting to know the reasons which led the designer to place the exhaust valve for the bottom cylinder on the top of the pocket. Would it not be advantageous to fit this valve at the bottom of the pocket, as then any unconsumed lubricating oil, or carbon, present in the cylinder would be cleared out through the exhaust valve instead of collecting in the lower part of the head next the piston rod stuffing-box.

It is interesting to learn that Messrs. Werkspoor are proceeding with an experimental double-acting two-cycle engine, and I trust that, when Mr. Lugt has concluded his experiments on this new machine, we shall have the pleasure of another visit from him, so that he may follow on with the third chapter mentioned in his paper.

Mr. J. C. M. Maclagan (Associate Member): As one who has had some experience of the working of Werkspoor Diesel engines before the war, I should like to contribute a few remarks to the discussion on Mr. Lugt's paper. In the first instance, Mr. Lugt and his company are to be particularly congratulated on their pioneer work in the field of Diesel engineering. They evidently appreciated the possibilities of the Diesel engine at an early date, when many people were still dubious as to its chance of success, and many others frankly hostile towards it.

One of the vessels fitted with Werkspoor engines, with which I had experience, was the "Emmanuel Nobel," and it will, I am sure, interest Mr. Lugt and the members of this Institution if I make a few remarks on the running of this vessel. I may say that I served as one of her complement in the year 1914, for a trip of about 12,000 miles. The few troubles experienced with her machinery are hardly worth

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Mr. J. C. M. Maclugan.

recapitulating to-day, as in cases where the defects were due to design the parts concerned have, generally speaking, been redesigned. Other troubles were due to the fact that experience with Diesel engines in service was not so complete then as now, and the necessity for regular examination and adjustment not so fully appreciated.

There is one characteristic of the "Emmanuel Nobel's" engines which gave a certain amount of trouble, and which is still retained in the present-day Werkspoor engine. It would be interesting to hear from Mr. Lugt if the difficulties associated with this part have been overcome. I refer to the method of distributing fuel from the fuel pump to the fuel-injection valves. The system which is illustrated in Fig. 2 differs fundamentally from that used on any other engine so far as I know. As already explained by Mr. Lugt, the pressure of supply of fuel to the fuel valves is limited to the static head obtained by placing the floating vessel some height above the cylinder tops, it being observed that the air pressure on top of the oil in the floating vessel is balanced by the air pressure in the fuel-valve cases. The pressure forcing the fuel through the very fine opening of the small fuel-regulating valves is, therefore, in the vicinity of 8 lbs. per square inch, and in my experience, even with carefully filtered fuel, the regulating valves become choked and the distribution of the fuel to the various cylinders irregular. These valves had to be regulated at very frequent intervals in the case of the vessel to which I refer. In most other engines each fuel valve has its own high-pressure pump, which is capable of exerting a pressure of, say, 1,000 lbs. per square inch in excess of the blast pressure, to overcome any tendency to obstruction in the fuel discharge system.

Another source of trouble in the fuel discharge system was the pump-plunger packing, which still appears to be retained. This had a tendency to score the pump rod very badly. In most modern engines the packing is dispensed with. I should

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Mr. J. C. M. Maclagan.

also like to know if, in the event of the floating vessel sticking in one position, any means are provided to prevent the fuel from rising sufficiently high in it as to overflow into the blast-air system.

Speaking generally of the Werkspoor single-acting engine, it is interesting to note that this engine, which at one time was a very light weight engine, is now made much heavier. The tendency with other four-cycle makers is very much in the other direction, and it would be interesting to know what Mr. Lugt's views are in the matter.

Referring to the double-acting engine, it is most interesting to note that Messrs. Werkspoor are keeping an open mind as to the cycle which should be adopted in this case. As the double-acting four-cycle engine described by Mr. Lugt develops in the bottom cylinder only 68 per cent. of the power developed in the top cylinder, and in the North British two-cycle double-acting type, for example, the power developed in the bottom cylinder is equal to that developed in the top, it can be stated definitely that there is much room for improvement in the double-acting four-cycle type described. Moreover, a two-cycle double-acting engine having, for example, three cylinders with six valves working continuously in these cylinders, can develop a greater power than a double-acting four-cycle engine of the type described, having six cylinders with sixty valves working continuously.

In his remarks, Mr. Lugt stated that the piston rod in the double-acting engine was remarkably cool to the touch when working under normal conditions. It must not be overlooked, however, that even at the bottom centre the part of the piston rod which may be felt is not by any means its hottest part. It is well known, for example, in the case of cylinder liners, that the temperature of the liner falls very quickly as the distance from the combustion end increases. The same argument will naturally hold good in the case of the piston rod.

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Mr. John S. Brown, M.B.E.

Mr. JOHN S. BROWN, M.B.E. (Member): This paper traces the progressive development in the design of an oil-engine which occupies a very prominent position in the marine engineering world. At all stages it has maintained a distinct individuality, and as it is one of the few designs not in the meantime directly represented in the Clyde area, there is a particular value in having this detailed description put at our disposal.

With the coming of the double-acting engine, introducing a new series of problems in cylinder construction, it is illuminating to study the detachable cylinder skirt which forms a well-tried feature of the normal engine, and has now been turned to further advantage in the double-acting design. The adoption of a jointed construction in the working surfaces of a cylinder is met with in other makes of engine, but surely none of them can make equal claims to the simplicity offered here. Fig. 3 shows a sharp contrast between the pistons of the early and the modern engines; this growth in the rigidity of the attachment between the piston and the piston-rod has been quite a general feature in other designs, and appears to arise from severe but indeterminate stresses due to distortion of the piston while at working temperature. On these grounds, in the double-acting engine, any similar piston fastening might become open to question, and it is unfortunate that the illustration in Fig. 16 does not bring out that the construction transfers both the top and bottom explosions as compression forces to a substantial flange, forged solid with the piston-rod and located between the two groups of rings. The cycle adopted on the underside of the piston is similar to those in the Doxford and Scott-Still engines, which is sufficient to confirm that the thermal efficiency is not detrimentally influenced by the low compression-pressure. Hence the cycle, as such, in no way restricts the rating. Presumably the moderate power taken from the underside of the piston arises from a conservative desire to keep both feet on solid ground

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while accumulating service experience from the more novel parts of the engine.

In the single-acting engines, the specific requirements of marine service are represented in the presence of reversing gear, which, here, has an attractive simplicity; and in the use of a pump-link drive for the blast compressor, so shortening the engine. The single fuel-pump in combination with the floating bottle on the fuel-delivery line gives a system with few parts, and it also provides a margin of time against a fuel shortage which will be appreciated by the *personnel*. To these features there is added the use of a fuel valve displaced from the centre of the cylinder. And, taken altogether, considerable interest should be derived from a study of the fuel performance on service; such figures are not available in the paper, and attention may, therefore, be drawn to the alternative source provided in a report about to be published by the Marine Oil-Engine Trials Committee. This report describes the trials made on a twin-screw installation of six-cylinder Werkspoor engines constructed by Messrs. Hawthorn, Leslie & Co., who are also licencees. The records include tests on oils of both Diesel and boiler grades, while the manœuvring and starting tests formed a very thorough trial of the novel features in the reversing and fuel systems. In the meantime it is impossible to refer to these results in detail, but Messrs. Hawthorn have reason to regard the performance as in every respect satisfactory.

Mr. W. E. Philbrow (Member): I am pleased to have the opportunity of joining with previous speakers in expressing admiration of the ability, original ingenuity, and courage displayed by Mr. Lugt and Messrs. Werkspoor in the pioneer work of developing the marine oil engine, and for the liberal information given in this paper. That their courageous policy has been justified is proved by the world-wide reputation and financial success they have secured, and it is to be hoped that

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Mr. W. E. Philbrow.

this success will encourage the leaders of British firms to change their present policy of adopting second-hand designs, inventions, and methods, and rely more on latent British talent, which was most assuredly the foundation of our one-time engineering supremacy. It is interesting to be reminded that prejudice against labour-saving methods is not confined to unskilled folk, and that intensively trained minds have also some unaccountable antagonism to any change in their methods. This is demonstrated in the disclosure of the necessity of discarding the successful, sane, automatic system of lubrication used in the first large engine, and the return to the hazardous feel and see-the-wheels-go-round custom of the engineers of that period.

Also, I think it should be admitted that even designers and others who have ample scope for peaceful, contemplative study suffer from prejudice too; and when designers of marine steam-engines tackled the marine oil-engine they were obviously antagonistic to changing their conception of cylinder and piston construction, and making use of the standardised design already established in the costly school of experience with land engines. In consequence much unnecessary time and money have been spent in passing through the same phases of development with the marine type of engine, for it should be remembered that the real difficulties met with in all internal-combustion engines are associated with the construction of the cylinders, pistons, and valves, these difficulties being common to both land and marine engines.

This point is manifest in the designs of the cylinder heads, Fig. 9, where the "old or original" type, comprising a heavy flat surface surrounded with heavy masses of metal at the joint, was adopted as standard marine practice of the period, whereas what is described as the "new" type had been already standardised for land practice from experience with hundreds of cylinder heads. In connection with the actual joint of the head to the liner, it will be seen that the bolts are totally

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inaccessible and in the water space, both objections which could be overcome by using tee-headed bolts, extended through the head with the nuts outside. This method is insisted on by most insurance companies.

Another point where a precedent had been established in land practice was the necessity for the most rigid construction possible in the framework, in place of the tie-rod method, and rigidity in the piston line, in place of what is theoretically necessary in the strength of the materials used, experience showing that, apart from the actual stresses arising from the momentum of the reciprocating parts, much larger stresses and violent vibrations were set up periodically, which caused endless minor, and at one time unaccountable, troubles in the working of the engines. An outstanding feature in the progress of the marine-oil engine is the increasing rigidity of the frames and bedplates, and the stiffening of the ship's structure under the engines.

The provision for the inspection of the piston is characteristic of the ingenuity and courage evident in all the designs, but it seems to me that more attention should be devoted to the combustion and the lubrication and packing of the piston to do away with the necessity for frequent inspection. Large numbers of pistons are running continuously in industrial works for months, without stopping for inspection purposes. The "Ramsbottom" piston ring was designed long ago to work in a mixture of steam and water, common to the locomotive of that period, the water forming a good seal through the back of the rings, but with the oil engine the piston rings have to work in a dry furnace, also acting as heat carriers, and oil scrapers under both high pressure and high speed, and there is certainly room for more advanced design in this most important detail.

The system of supplying fuel to the sprays under steady pressure from a reservoir should ensure most economical running, in addition to reducing the cost and complication of

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Mr. W. E. Philbrow.

numerous pumps, and it seems rather a retrograde step to revert to separate pumps in the double-acting engine; perhaps Mr. Lugt will be good enough to supply comparative fuel consumption records with both types of supply.

The unique system of operating the double-acting engine with ignition at constant pressure in the top end, and ignition at constant volume in the bottom end of the cylinder, is again characteristic of the courageous policy followed throughout the development of these engines; and it would add to the value of this paper if Mr. Lugt would submit some comparative data relative to the working pressures, temperatures, fuel consumption, and turning-moment obtained under such working conditions.

The ingenious valve arrangement used at the top end of the double-acting cylinder appears largely to overcome the principal objection to double-purpose valves, that is, the large volume of exhaust gases remaining in the passages, which are returned into the cylinder during the suction stroke, the passages in this design being very short.

The difficulties suggested by Mr. Lugt, arising from the use of a 7-inch nut to fasten the rod to the crosshead, again tempts me to ask: Why retain this method of fastening when there are others of proved working efficiency, such as the tapered cotter wedge, which can be removed readily with the normal equipment of a ship's engine-room?

One unexpected virtue of the double-acting engine which has confounded all the Jeremiah prophets is the satisfactory working of the piston rods and packings, which has proved to be one of the most reliable details; and I suggest the pocket formed in the cover is more a source of danger than an advantage, also that there is no necessity to reduce the mean effective pressure in the bottom end of the cylinder, which, in combination with the reduction of the effective area by the piston rod, must reduce the power some 30 per cent., and give a very uneven turning-moment to the crank. Pos-

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sibly the need of even torque is not of any great consequence in the actual running of the ship, but I would point out that variations in the individual torque from each crank add to the working stresses of the framework, shaft, hull, and propeller, and consideration of this problem raises in turn the question of the best possible combination of cylinders to secure all-round efficiency.

In land practice with four-cycle engines, the single-acting tandem arrangement of cylinders has entirely superseded the inverted double-acting cylinder, and I submit the tandem type has several practical advantages. Considering a four-cylinder combination, the final mean torque will be more regular, and the individual torque from each crank will be in regular sequence each revolution; also the diameter of the lower cylinder can be increased to compensate for the area of the rod, ensuring equal power from each cylinder; the rod packing is more accessible, and not liable to damage from falling particles of carbon; both pistons can be observed while running, and inspected without breaking any pressure joints. In his final remarks Mr. Lugt mentions the prospects of using the two-stroke cycle, and I suggest that the problem of securing more regular torque will eventually make the use of this cycle a standard for marine work, and for all engines using separately injected fuel.

Objections are offered that the increase of power is not what it should be, but this increase, even with the normal design using a deflector piston overrunning both inlet and exhaust ports, is some 35 per cent. over the equivalent four-cycle engine, while the impulses come in regular intervals at each half-revolution of the crank, ensuring more regular stresses in the motion and framework. In the light of our present knowledge, the four-stroke cycle is only justified in engines obliged to use fuel directly mixed with the incoming air, and for that condition of fuel supply the four-stroke cycle is unrivalled.

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Mr. C. R. H. Bonn.

Mr. C. R. H. Bonn (Associate Member): I have been particularly impressed by the ingenious and cleverly worked out new valve gear shown by Mr. Lugt. It is obvious, from an inspection of the catalogue of the leading types of valve gear given, that other arrangements are possible, and such may have occurred to Diesel engineers. In particular, it is possible to have a rocking arrangement. After the manifestations of Dutch ability and thoroughness witnessed during the last few years, I have some hesitation in attempting to criticise Dutch design. It is stated in the paper that one of the main aims of the design has been to follow, as far as possible, steam-engine practice. A rocking arrangement can be actuated by the ordinary link-motion gear, and thus be more consistent with the aim expressed. It would, therefore, be interesting to learn if this type has been considered, and if so, why it has not been adopted.

In ordinary practice, with a fast-running engine, the camshaft must be rotated, but in the case of a marine Diesel engine, running at something under 200 r.p.m., it is not necessary to rotate it. Fig. 27 illustrates a proposed rocking arrangement, in which the camshafts are actuated and reversed by means of the ordinary link-motion gear run from the half-motion shaft. The air-starting levers can be pivoted on eccentrics fixed to the fulcrum shaft, and can be put in or out of action by rotating this shaft. It is apparent that two camshafts are required, one carrying the inlet firing air cams, and the other the exhaust. There is thus in effect the same number of shafts, with the advantage of an immensely simplified system of levers, and an arrangement which, I submit, would be more readily understood by the average marine engineer. There may be objections to the proposal, but, on the other hand, it may have considerable advantages as regards ease of control. It appears to me astonishing that the simplest possible arrangement of valve gear for reversing purposes has been either missed or totally neglected by Diesel designers.

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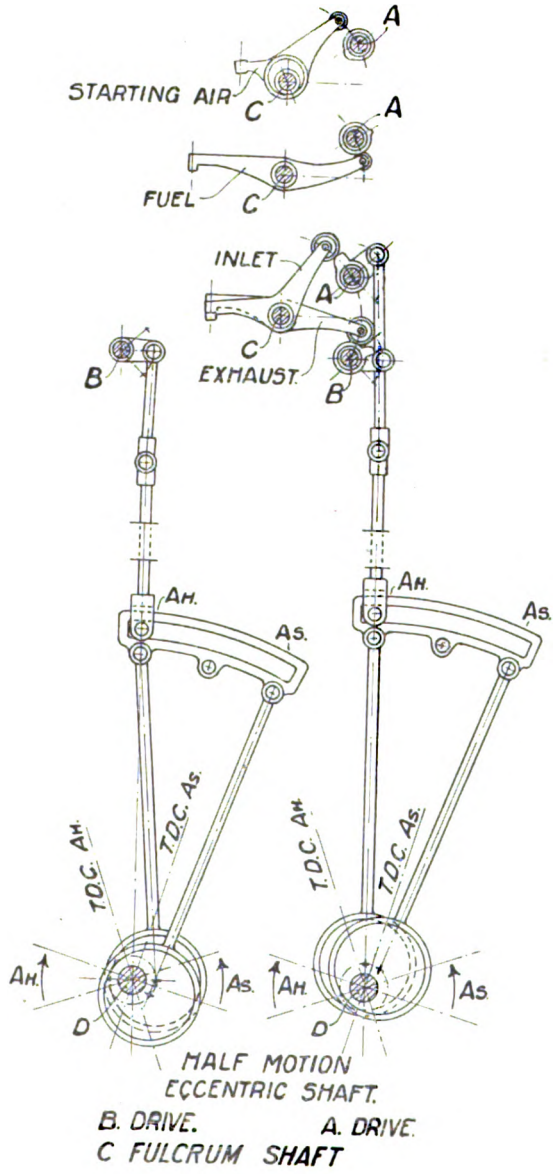

Fig. 27.

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Mr. C. R. H. Bonn.

Mr. Lugt's admirable paper once more brings into contrast the readiness of Continental Diesel manufacturers to disclose details of design, as compared with the reluctance of British Diesel manufacturers to give any information. Once, when visiting a Continental factory, I asked the manager if it paid to give away so much information to possible competitors. His reply was characteristic. He said: "Anyone who is in a position to compete with us can buy our machines and copy them. It is not, however, simply a case of copying our machines. Efficient manufacture is impossible to-day without special machinery, and this machinery requires a long time to prepare. By the time our competitors could produce this machinery, we would have, in the ordinary course of events, so improved our production that they would have to start all over again. If we were not continually improving in this way, we should not be able to stay in business a year. So, far from doing us any harm, it is a very good advertisement for us to have people to see over our works." Naturally such an argument appeals only to those whose production methods are up-to-date. No doubt Mr. Lugt will be amply rewarded for the trouble he has taken in putting before us his very fine description of the Werkspoor Diesel engine.

Mr. Archibald Rennie (Member): In his brief résumé of the development of the Werkspoor Diesel engine, Mr. Lugt touches upon some interesting features. It is a tribute to the progressive spirit of the Werkspoor Engine Works that they adopted forced lubrication in their first engine, although subsequently compelled to depart from it for a time, doubtless as a concession to sentiment and in an endeavour to reduce the first cost of their engine. The advance from 100 i.h.p. per cylinder, as in the "Vulcanus," to 1,000 i.h.p. in the double-acting engine, with a reduction in revolutions from 175 to about 100 per minute, is a good illustration of the remarkable progress that has been made in oil

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Mr. Archibald Rennie.

engine design and construction during the past 15 or 16 years.

I agree with Mr. Lugt in emphasising the importance of keeping the pistons in good working condition, as failure here brings in its train many evils, *e.g.*, loss of compression and bad combustion, escape of gases, heavy lubricating-oil consumption, etc. In this connection, it would add to the value of his paper if he would say exactly what is the minimum distance as a function of the stroke, which he has found from experience to be best for the position of the top ring. On the question of piston cooling, I would like to know what Mr. Lugt's views are about oil as against water for the cooling medium. It is quite apparent from his paper that he prefers water, but his experience with oil cooling—and I presume he has had some—would be of value.

In passing to a description of the Werkspoor double-acting engine, Mr. Lugt again keeps piston considerations well to the front, and draws particular attention to the provision made for the examination of this very important member. I should think, however, that the handling of such heavy weights as the bottom cylinder, and a piston and rod of over four tons, is not an easy matter at the best, and will be done as seldom as possible on board ship. Indeed it looks as if the designers have made a virtue of necessity in this matter, since more work would apparently be entailed by taking the piston and rod out from above. The question of dealing satisfactorily with a 7-inch piston rod nut on the crosshead end of a reciprocating steam-engine is not a difficult one, and should be no more difficult in an oil engine. It should not of itself be allowed to determine the method of examination and overhaul, as appears to be the impression conveyed by the paper.

The problem of making a satisfactory four-stroke cycle double-acting engine can apparently most easily be solved by producing combustion of the fuel in a chamber apart from

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Mr. Archibald Rennie.
the lower cylinder itself, and, while there can be no objection to this as a working principle, it appears largely to determine and explain the reason for the relatively small power obtained from the lower cylinder in four-stroke cycle engines. The method adopted by Werkspoor for heating the lower cylinder when starting up, so that the fuel when introduced may be ignited under a compression pressure of about 300 lbs. per square inch, is quite ingenious. It follows from this, however, that when manœuvring, the engine can only be depended upon to function as a single-acting engine; this, I should say, is a disadvantage. Another peculiar feature of the double-acting four-stroke cycle engine seems to be that the impulse or firing strokes do not follow each other at regular intervals of 360 degrees of crank angle, but at intervals of 180 degrees and 540 degrees respectively. A little consideration will show that this cannot be avoided in a four-stroke cycle engine, but it, nevertheless, does not give such an even turning crank effort as could be desired.

It would add to the value of the paper if Mr. Lugt would give some particulars of the actual quantities of steam raised in boilers by the use of exhaust gases from his engines, stating this, say, in terms of lbs. per b.h.p. or i.h.p. per hour. Further, I was struck with the absence in the paper of some results from the performance of typical Werkspoor engines, and particularly of the double-acting engine. Notwithstanding, Mr. Lugt is to be congratulated on having given to the Institution an interesting and informative paper, and it is pleasing to note that, although one of the pioneers in the development of the four-stroke cycle engine, the Werkspoor Engine Works are not blind to the possibilities of the two-stroke cycle engine, and appear to think that possibly the future lies with that type of engine, especially in its double-acting form, since they are now constructing a large unit of that type in their works, about which we shall hope to hear more in the future.

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Mr. Otto Kahrs.

Mr. Otto Kahrs (Member): The system of getting at the pistons of the single-acting engines is certainly the most convenient at present existing, but I wonder if, in some cases, it might not be advisable to water cool the extension also. In Fig. 3 the new design on the right is certainly a great improvement, as it brings the piston rings much further down, and I am inclined to believe the reason mentioned by Mr. Lugt, namely, that the lubricated cylinder well must not be exposed as long as fuel is still being injected, is not the only factor of importance. Certainly the piston rings are much better cooled with the new pattern, and also the distortion of the upper end of the piston, owing to the heating up of the top, may have some influence on the correct working of the rings in the old model. I, therefore, think the new design is a great improvement, on which Mr. Lugt is to be congratulated. It would be interesting to hear, however, the motive for changing the internal design. I quite see certain advantages, but is not the newer one more difficult to inspect and clean internally, as far as the outside core is concerned? It would also be interesting to hear Mr. Lugt's opinion on the various kinds of piston rings. Does he think, for instance, that the inside hammered rings made by certain specialists are a great improvement on the ordinary rings? I quite agree with Mr. Lugt respecting the importance of sufficient dimensions of the bolts connecting the pistons to the rods, as the piston may, for instance, seize, and although this may be quite a remote chance, it ought to be provided for, and I am inclined to believe that bolts should be dimensioned practically as large as on a double-acting engine. This, of course, also applies to the bolts for both ends of the connecting rod, and for the main bearings. The design for fuel distribution is most interesting, and has certain good points, but I am inclined to believe that independent pumps are to be preferred. It must be remembered that the pumps should not only bring the fuel oil to the fuel valves at the right time, but also in the

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Mr. Otto Kahrs.

right quantity, and as a measuring instrument the independent pumps certainly score on the adjustable needle-valves required with the Werkspoor arrangement. Experience proves that this has to be adjusted fairly frequently if an equal division of load is to be maintained, and although this is certainly more easily done than adjusting an independent pump, the risk of overloaded cylinders is undoubtedly much larger with adjustable needle-valves, and the ordinary engine-room *personnel* are certainly human beings, and thus liable to err sometimes.

Regarding the design of the new six-valve cylinder head, I think Mr. Lugt could greatly facilitate the understanding of the paper by adding a sectional drawing and a photo of the valve gear in position. Perhaps Mr. Lugt could see his way to introduce this in his reply to the discussion.

With respect to the piston-cooling arrangement on the double-acting engine, it would be interesting to hear what type of packing is used, and what its probable term of life will be.

Mr. Lugt does not make any mention of a couple of the most important points of the design. I allude to the air compression and its drive, valves, and coolers, and should be much interested to hear Mr. Lugt's ideas on these points. Is the omission to be so understood that Mr. Lugt thinks mechanical airless injection will be the solution, even in the immediate future?

I understand that the cylinder covers on the "Varanger" have all been changed, and an improved design introduced owing to the development of certain cracks, and in this connection it would certainly be very interesting if Mr. Lugt would be kind enough to give particulars of the changes made in design, and if possible with sketches.

Mr. JOHN TINDALE: Perhaps some particulars of what is being done with this particular type of engine by British firms

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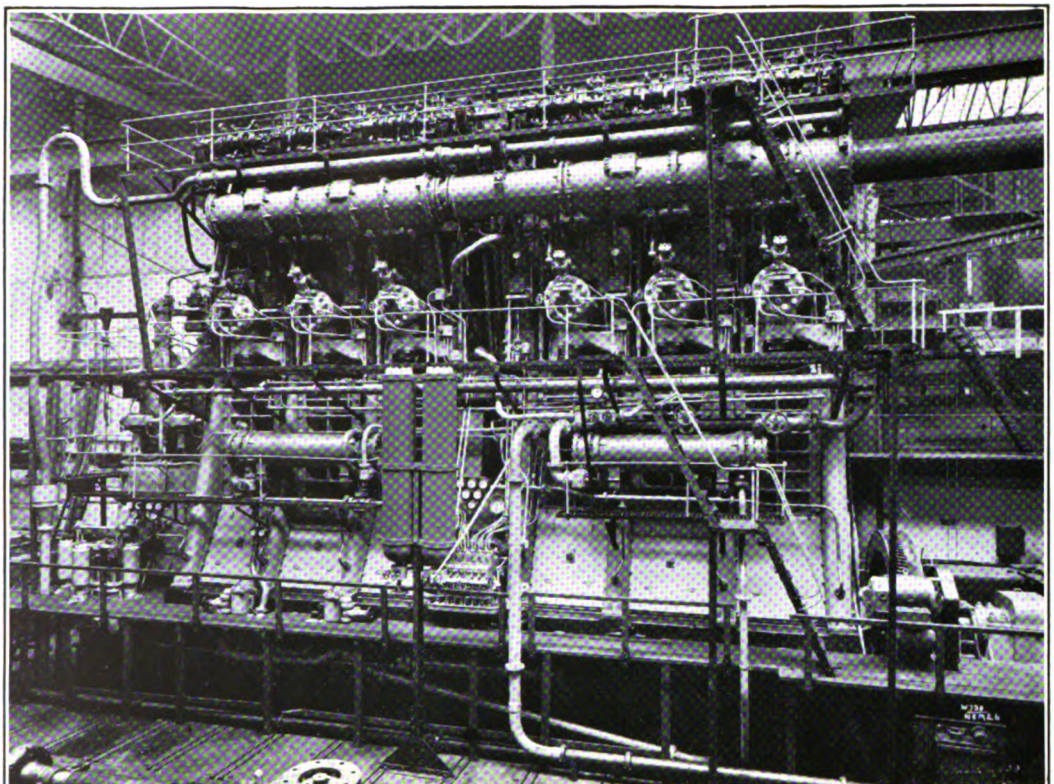

Fig. 28.

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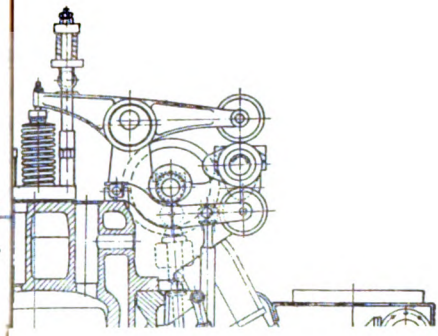
FOUR STROKE



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Mr. John Tindale.

may prove of interest to members of the Institution. Referring to the double-acting engines described by Mr. Lugt, four sets are under construction by the North-Eastern Marine Engineering Co., Ltd., Wallsend-on-Tyne, to the order of Messrs. The Anglo-Saxon Petroleum Co., Ltd., London. Also at this moment a large engine of 5,000 i.h.p. and of similar dimensions, but with the well-known North-Eastern-Werkspoor cylinder head, with separate inlet and outlet valves, is about to undergo shop trials, having been built to the order of Messrs. Alfred Holt & Co. Fig. 28 illustrates these engines in the erecting shop, and a general arrangement is given in Fig. 29.

Mention might be made of the "Raby Castle," a single-screw cargo vessel of 8,000 tons deadweight, propelled by an eight-cylinder single-acting Diesel engine of the latest North-Eastern-Werkspoor design, built to the order of Messrs. Chambers, Liverpool. Each cylinder is 730 mm. (28·7 inches) in diameter, with a piston stroke of 1,300 mm. (51·18 inches), and the engine develops 3,000 i.h.p. when running at a speed of 92 r.p.m. This vessel was put into service in May, 1925, her average loaded performance being 11 knots on 9 tons of fuel oil per day. The fuel coefficient, $\frac{D^2 \times V^3}{\text{Tons fuel per day}}$, is 82,420, and the consumption of lubricating oil is 14 gallons per day for all purposes. This vessel is fitted with electrical auxiliaries, and the machinery is giving every satisfaction.

Regarding the utilisation of the waste heat carried off by the exhaust gases, touched upon in the paper, when it is already necessary to provide boilers and steam auxiliaries, for example, in oil-carrying vessels, very little alteration is required in the design of ordinary Scotch boilers to equip them for the efficient raising of steam by this means. One case may be cited, the "Wellfield," which is fitted with twin-screw engines of the standard six-cylinder North-Eastern-Werkspoor type, the cylinder bore being 560 mm. (22·05 inches) in diameter, the piston stroke 1,000 mm. (39·37 inches), and

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the r.p.m. about 120. Two boilers are provided, each having two furnaces which are fitted with White's patent oil-burning gear for port use. Connections are also made from the main exhaust pipe for ordinary voyage conditions, by which sufficient steam is raised for working the dynamo, feed pumps, air pump, centrifugal circulating-pump, steering gear, and an exhaust steam feed-heater. Indeed, so much steam was generated that after the first voyage it was deemed advisable to fit a by-pass connection so that a portion of the exhaust gas could escape direct to the funnel. This arrangement saves about 1½ ton of boiler oil-fuel per day, which, at the price of 85s. per ton and assuming about 270 steaming days, means a saving to the shipowner of no less than £1,720 per annum, a not inconsiderable item. Two further points are that the boilers require little or no attention while raising steam in this way, and they form an excellent silencer.

Mr. JOHN GALBRAITH (Member): The right-hand illustration, in Fig. 3, shows the piston of the present single-acting engine, where the cooling water enters the piston from a tube with a bent nozzle. The water circulates round the annulus between the outer wall of the piston and the conical centre portion, and then passes into the central space through a hole diametrically opposite to the inlet. The outlet from the central space is on the same side as the inlet. From the position of the outlet hole on the side of the conical centre position, it appears that the level of the water in the central space would be well below the metal of the piston crown, and might lead to overheating of the piston, particularly when the engines were working at low revolutions. It would be interesting to know what ready means are provided for draining the piston, and also for removing any deposit which may be found in the annular space between the conical centre walls and the outer wall of the piston.

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Mr. Lugt states that the type of fuel pump used for the single-acting engine is not suitable for the double-acting engine, a separate pump being used for each cylinder in the latter. Would the single-acting engine system not be suitable if two floating reservoirs were used, one arranged for the top fuel-valves and one for the bottom fuel-valves, with regulating valves, etc., to correspond? He says his fuel-pump system was designed to overcome the primary difficulties of starting up, due to faults in the working of the fuel pump. A quantity of fuel under pressure is kept ready to be conveyed to the engine. In the usual arrangement with a pump plunger to each cylinder, when first starting up, the fuel piping is primed, and, if by chance it becomes partially emptied when manœuvring, is filled up by a few strokes of the pump while the engine is on air, but with the fuel pump working. All controlling and cutting-out is performed by lifting the suction valve.

In Mr. Lugt's system there is a hand throttle controlling the supply to both engines, a master valve on each distributing box, and an individual valve regulating the supply to each cylinder. In addition to the nine valves described as needle-valves, there are at least two automatic valves cutting off the supply when the engines are stopped, in order to prevent flooding of the system. While the pump itself has been simplified, the individual plungers being replaced by one large one, the general arrangement has been made more complicated.

The governor does not appear to be very sensitive; it does not cut out one cylinder at a time, but all six cylinders at once. The latest piston, Fig. 3, shows short double-nutted bolts, with a deep nut and a lock nut on the bottom. It is usually considered desirable, however, to fit long studs or bolts to permit of a certain amount of stretch.

On page 429 Mr. Lugt describes the system of dismantling the piston which is a feature of the Werkspoor engine, and while this method provides a ready means of examining and dismantling the piston, access for examination of the cylinder

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Mr. John Galbraith.

liner for wear does not appear to be so good as in the usual method of lifting the cylinder cover. In the latter method the pistons can be readily brought above the level of the cylinder, when the rings can be examined and renewed if required. Of course, in the Werkspoor engine the cylinder cover cannot be removed without also withdrawing the cylinder liner.

The new type of cylinder cover, Fig. 9, shows the joint between the cover and the piston to be entirely contained within the cooling-water space. From the construction of this joint, it appears that the bolts are exposed to the corrosive action of cooling water, not only on the heads and nuts, but on practically the entire surface of the bolts, and they would, therefore, deteriorate rapidly in service, more especially when sea-water was used for cooling purposes. Failure of this joint might have disastrous consequences, and a considerable amount of work would be entailed in remaking it. Perhaps Mr. Lugt will state whether the bolts of this joint are made from any special material, or if any trouble has been experienced with it after considerable periods of service.

In the double-acting engine, the chamber in the bottom cover, designed to protect the stuffing-box, and into which the enlarged part of the piston rod enters with a fine clearance, would appear to be a possible source of danger if the space got filled up with carbon or other deposit. In the event of a bottom fuel-valve becoming leaky, the fuel would accumulate in the combustion chamber on top of the air-inlet valve, and on the valve being opened it would pass into the suction pipe. As on starting up the exhaust gases from the top are passed through this pipe, there would be danger of fire in the suction pipe.

Mr. LUGT: I quite agree with Mr. Richardson that the system of combined inlet and exhaust valves has important advantages. However, although it was adopted in the

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case of the double-acting engines now being built for the 10,000-ton tankers for the Anglo-Saxon Petroleum Co., which is a special case, we continue to make separate inlet and exhaust valves on our standard engines. I do not admit that if it is the best system for the top of the cylinder it is necessarily also the best for the bottom of a cylinder of a double-acting engine. In the case of the Werkspoor type of double-acting engine, the separate valves were considered preferable for the bottom, as the conditions of accommodation of the valves and of heat stresses at the bottom are quite different from those at the top.

I wish to thank Mr. Fulton for his kind remarks about the Werkspoor engines. In reply to his question, why the type of fuel pump used on single-acting engines is not suitable for double-acting engines, I may say that in the system described the speed of the single-acting engine is controlled by a throttle valve, which regulates the total quantity of fuel going to the several cylinders. In this case, the speed is a function of the opening of the one throttle valve. In the double-acting engine, however, the speed depends on the variable load carried on both ends of the cylinders, and a regulation with two throttle valves may lead to the overloading of either the one or the other end of the cylinder. It is, therefore, necessary to regulate the quantity of fuel going to each cylinder at the top and bottom for each working stroke. No trouble is anticipated with the piston-rod packing at higher pressures; the bottom cylinder has actually been designed for maximum pressures of 500 lbs. per square inch in the latest type of double-acting engine. That no trouble arises is due to the construction of the combustion chamber and piston, and to the low compression and timing of the fuel, giving the card reproduced in Fig. 19. The separate combustion chamber with its large clearance volume gives on the one hand the low compression, and on the other hand very accessible valves, a simple valve gear, and a simple bottom cylinder-cover.

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Mr. G. J. Lugt.

The open machine with sight feed lubrication was made with a view to enabling the engineers to see and feel the moving parts, as is usual on steam-engines. It was found, however, that the conditions on a Diesel engine, which usually runs at a much higher speed, are quite different, and that forced lubrication was to be preferred. Very often sea-water found its way into the open framing, causing deterioration of the lubricating oil, with, as a consequence, heavy wear of the main bearings, and ultimately the breaking of crankshafts.

With reference to Mr. Love's remarks concerning the joint in the water-jacket space, I beg to point out that this joint is one which never needs to be broken, and consequently needs no remaking. It can be tested for tightness before putting the cylinder into the jacket. Besides, the forces acting on the joint are comparatively small.

In Fig. 6, Mr. Love will find a master valve on each distributing box. These master valves are automatically closed when the engine is stopped, so no flooding of the fuel valves is possible if the throttle valve is left open. As a matter of fact, the latter valve is often kept open by the engineers when manœuvring. The exhaust valve for the bottom cylinder was placed on top for two reasons, the first being that this valve is more often dismantled than the inlet valve, and, therefore, should be placed in the most accessible position, the second being the connection to the exhaust manifold, which is situated in the middle between the top and bottom of the cylinder.

I appreciate that Mr. Maclagan only refers to one of the minor troubles encountered in the machinery of the "Emanuel Nobel," and I am glad to see that he realises that the other troubles have been successfully overcome in the present-day engine. I am also glad to be able to inform Mr. Maclagan that this minor trouble has been overcome, and in a very simple way. The old type of fuel-regulating valve was a conically shaped needle-valve which was only about 0·004 inch

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off its seat when opened up for full load. Even very small particles in the oil would gradually choke it. It is now replaced by a cylindrical needle with a divergent groove of triangular shape, which can never get choked, see Fig. 30.

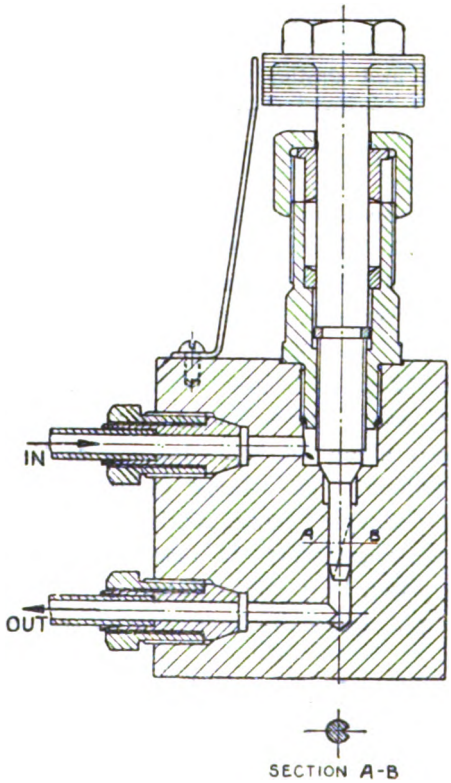

Fig. 30.

With this type of distributing valve, practically no regulating is necessary.

Although the pump-plunger packing is, as a rule, dispensed with in solid injection engines, it is still generally used for the ordinary kind of fuel pump. A suitable packing, however,

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Mr. G. J. Lugt.

will not cause the plunger to be scored or to wear to any great extent. The arrangement of the floating vessel is such that sticking in one position is practically impossible; therefore, no overflowing into the blast-air pipe is to be feared.

With respect to the weight of the engine, it must be conceded that the present-day engine is heavier than the original type of engine; it is, however, not made heavier than engines of other makes and similar type. On the other hand, Mr. Maclagan may be assured that the size of different scantlings would not have been increased if experience had not proved it to be necessary.

To find the temperature of the piston-rod flange, holes were drilled in it, into which pieces of low fusing metal were inserted. None of the metal has run out, which shows that the temperature remains below 180 degrees F.

Mr. Brown is not quite right when he states that the piston-rod flange is located between the two groups of rings. In fact, the piston is bolted on top of the flange, see Fig. 16, in very much the same manner as the piston of a single-acting engine. The flange diameter is about equal to the piston diameter; consequently the piston bolts have theoretically no other strain to take than that due to the inertia of the piston body. The flange itself, which is forged solid with the rod, takes the forces due to the combustion in the bottom.

As to the power taken from the underside of the cylinder, we have been conservative indeed; there is, however, every reason to believe that higher mean-pressures can be allowed in service. This, however, is a matter of experience, and it was felt undesirable to overrate the engines from the beginning.

I thank Mr. Philbrow for his kind remarks regarding the work done by Messrs. Werkspoor and the part I have taken in it. With respect to his objection against the submerged flange, I beg to refer him to Mr. Robert Love's remarks and my reply thereto. I fully agree with Mr. Philbrow when he

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says that in the first place attention should be devoted to combustion, lubrication, etc., and if he will read over the part of my paper relative to this matter he will see that we are both of one opinion.

Mr. Philbrow asks me to submit comparative data relative to the working of the top and bottom end of the cylinder. This will certainly be done as soon as one of the engines under construction has been on the test-bed. For the present, I can only refer to the official trials made by Prof. Hawkes on the experimental unit, installed in the Wallsend works of the North-Eastern Marine Engineering Co., and published in "Engineering" of 13th June, 1924.

I doubt whether the fastening of the piston rod to the crosshead by means of a tapered cotter wedge, as suggested by Mr. Philbrow, would be satisfactory. The forces working on the crosshead at the top and bottom are respectively about 200 and 150 tons, and a wedge for the latter force would have to have dimensions not at all compatible with the general proportions of the engine.

I do not see why the pocket in the cover should be a source of danger, and it certainly is an effective means of protecting the stuffing-box. The turning-moment of a double-acting engine is naturally more even than the turning-moment of a single-acting one of the same power, and I do not share Mr. Philbrow's apprehensions about the unevenness of the torque. I certainly do not believe that securing a regular torque will be an argument of any importance for the use of the double-acting two-stroke cycle.

I am indebted to Mr. Bonn for a suggestion which he claims to have considerable advantages for reversing, as regards ease of control, over other systems. Whether it is really a simpler system than any of the existing reversing systems can only be ascertained by incorporating it in the design of some particular type of engine. I must say that his diagrammatic sketch has not convinced me that the system suggested

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Mr. G. J. Lugt.

by him is simpler or cheaper to make than the Werkspoor system, or, for that matter, any other reversing system I know of.

Mr. Rennie demands an exact statement about the position of the top ring. I think that I have exactly defined it by saying that the lubricated cylinder wall should not be exposed when the fuel is being injected. This means that it is not only a function of the stroke, but also of the ratio between the stroke and the length of the connecting rod and of the length of the fuel cam. I am sorry to disappoint Mr. Rennie on the matter of expressing an opinion about oil cooling, as so far, in the Werkspoor engine, only oil cooling in pistons of the plunger type of relatively small size has been used, and I have no experience with the large crosshead type of engine.

The method of examining the piston is illustrated in Fig. 17, and if Mr. Rennie will read again the description he will see that the lowering of the bottom cylinder is effected by resting it on the crosshead by means of a removable bushing, and then turning the engine. This procedure is very easy and simple; as a rule the piston will not be disconnected from the rod, and no handling of heavy parts is required. The inspection and removal of piston rings is possible without taking the piston and the rod out of the engine. Even if dealing with the piston rod nut should prove an easy matter, which I doubt, the Werkspoor method of dismantling the piston will be simpler than lifting the piston and the rod out of the cylinder.

Concerning Mr. Rennie's remarks about the turning-moment, I beg to refer him to my answer to Mr. Philbrow's remarks on this subject.

As to the actual quantities of steam raised by the use of exhaust gases, I may say that Mr. Tindale's contribution to my paper contains some valuable information. The exhaust gases contain about 30 per cent. of the heat value

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of the fuel, and if they leave the engine at, say, about 700 degrees and the funnel at about 400 degrees F., it is an easy matter to calculate the quantity of steam which can be raised in a boiler suitably arranged for the purpose.

Regarding the performance of Werkspoor engines, I may say that the motor tanker "Nordanger" uses about 0·29 lb. of fuel per i.h.p., the total daily fuel consumption for an output of about 3,000 b.h.p. being 13 tons. The daily cylinder lubricating oil consumption is less than 4·5 gallons for the 12 cylinders. A complete log of one voyage of the "Nordanger" from San Pedro to London was published in "The Motor Ship" (London) of November, 1925. No working results of double-acting engines are as yet available, as the first of these engines is not yet installed.

Mr. Kahrs suggests that water cooling of the extension pieces would be advisable, but, generally speaking, this has not been found necessary, although provision for it has been made in some cases. The extension pieces of the engine shown in Fig. 14a are water cooled; engines, however, have been constructed of the same and even larger size with non-cooled extension pieces, and this has not caused any trouble.

In the internal construction of the new type of piston the principal object was to do away with radial ribs; the inspecting and cleaning of the external core is not more difficult than was the case with the old type piston. A number of plugs is provided for this purpose. Incidentally, I may say that usually the amount of scale formed in pistons is remarkably small. Very good results have been obtained with inside hammered rings, provided they are made of suitable material.

I do not agree with Mr. Kahrs in his appreciation of the independent pumps as compared to the adjustable needle-valves. With the latest type of needle-valves, adjustment for the purpose of obtaining an equal division of load is very rarely necessary. Only a change in the viscosity of the fuel may necessitate an adjustment of the needles. An unmis-

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Mr. G. J. Lust

takable check on the correctness of the adjustment is the exhaust temperatures of the cylinders. I hope that Fig. 31, showing a section of the new type of cylinder head, will be a help to the understanding of the description given in the paper

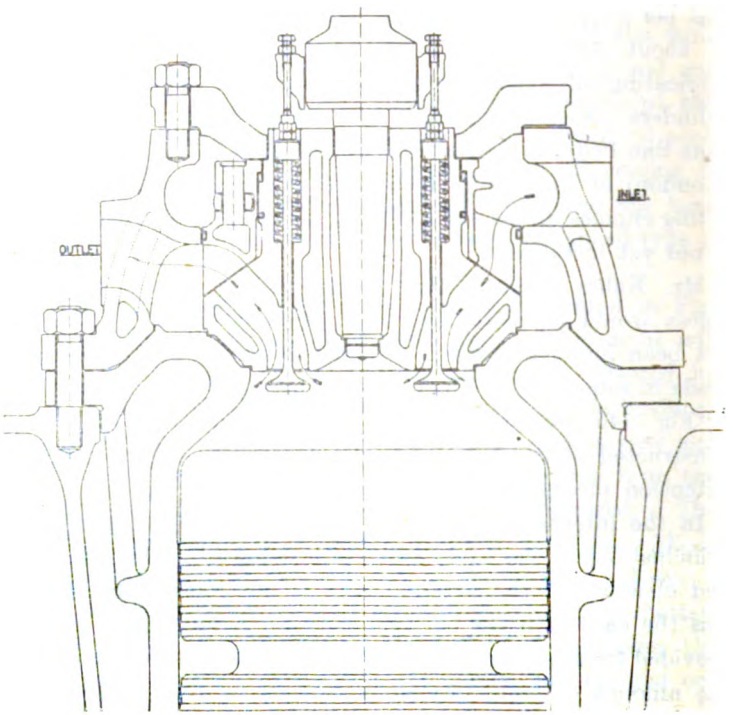

Fig. 31.

Although I think that there is a future for mechanical airless injection, and very good results have been obtained with it, the reason that I did not include in my paper a description of air compressors is the desire to keep the paper as concise as possible. However, it goes without saying that the compressor is a very essential part of the Diesel engine, and that

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the successful working of the engine is largely dependent on the reliability of the compressor.

The cracks which developed in the "Varanger" cylinders were of a very peculiar nature, and purely the consequence of a combination of unhappy circumstances. They were not of a nature to disclose a weakness in the design of the cylinder covers; they only showed how an apparently insignificant change in methods or materials may have very grave results. On the first voyage out of the "Varanger" the engineers reported that the packing between the cylinder cover flange and the cylinder beam was working out, and that the joints started to leak. In order to prevent this leakage, the engineers continuously hammered down the nuts on the flanges. As the latter had a very uneven support owing to the dissolving packing (which proved to be of very inferior quality), the flanges cracked at the places marked with a ✦, Fig. 32. Unfortunately the fillets which ought to have been there were locally turned away to a sharp corner, and the cracks naturally started in this corner at a place where the elasticity of the wall was impaired by the presence of a rib.

The new covers differ from the old ones in the size of the fillet, which is now made in such a manner that it cannot be machined away. The packing underneath the flange is left out entirely, and superseded by a rubber joint round the spigot. The stresses in the flanges and outside walls of the cylinder cover were carefully investigated under a hydraulic pressure, equal to the maximum combustion pressure, by means of an Okhuyzen extensometer. It was found that these stresses vary to a very marked degree with the hammering down of the holding-down bolts and with the elasticity of the packing. With no packing and the nuts hammered down the stresses are a minimum; a soft packing or loose nuts will cause stresses at certain places which may surpass the fatigue limit of the material. Incidentally, these investigations show that the extensometer is a very valuable and reliable instrument for

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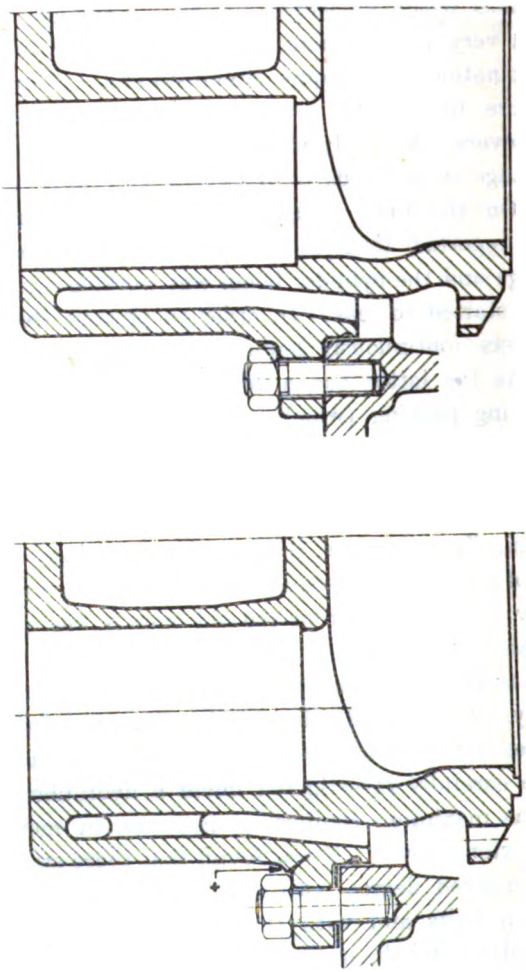

Fig. 32.

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testing castings of new construction which are subjected to heavy strains, and that it indicates with infallible certainty the places where high stresses, which might endanger the life of a casting, occur.

I am indebted to Mr. Tindale for his valuable contribution to my paper.

With the open system of piston cooling as used on our single-acting engines, the piston is not quite full of water, and this is, therefore, constantly being thrown up and down inside the piston. A simple calculation shows that only at very reduced speed is the acceleration of the piston at the top centre equal to the acceleration of gravity. Even if the engine can be made to run at this speed (about 30 per cent. of the normal revolutions), the load is then so small that no cooling would be necessary, provided the load is not concentrated on a reduced number of cylinders. Accidents of the nature Mr. Galbraith conceives have never happened on Werkspoor engines.

Deposits in the piston can be removed through plug holes in the bottom. If the temperature of the cooling water is kept below 120 degrees F., practically no deposit forms inside the piston. For draining the piston, a cock or screw plug is provided. The reason why the type of fuel pump used for the single-acting engine is not suitable for the double-acting engine is given in my answer to the same question asked by Mr. Fulton.

Mr. Galbraith's comparison between the Werkspoor system of fuel supply and the system with an individual pump for each cylinder is not quite fair It is not claimed that the former system is less complicated in the sense that it is cheaper to make, but it contains fewer parts which require attention and overhaul than the latter. There is only one high-pressure stuffing-box and two valves to look after; the needle-valves and master valves require no attention whatever. Moreover, a leaking valve has no influence on the speed of the engine

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Mr. G. J. Lugt.
or the distribution of the load over the cylinders. If the leakage gets so serious that the pump fails to keep the high-pressure reservoir filled, the spare pump is used, and the faulty one can be overhauled while the engine is running.

The governor shuts off a master valve in the fuel pipe; however, a by-pass is provided which allows a sufficient quantity of fuel to get to the cylinders to keep the engine going at reduced speed.

Evidently my conception and Mr. Galbraith's conception of a long and a short bolt differ. The bolts shown in Fig. 3 were intended to be long in order to permit a certain amount of stretch, the cylindrical part of the bottom nut not being threaded.

It is admitted that the examination of the cylinder liner is not as easy as with the method of lifting the cylinder cover, the piston having to be dismounted for the purpose. However, the extra work caused thereby does not take much time, and this is not considered a serious objection. The bolts and nuts of the submerged joint are made of non-corrosive material, and no trouble has been experienced with either the joint or the bolts.

The clearance of the enlarged part of the piston rod in the bottom cover is not as fine as Mr. Galbraith imagines, and sufficient space has been left underneath the shoulder to allow for some deposit. Means have been provided, however, to blow this deposit off. Even if it were possible for a considerable quantity of fuel to pass into the suction air pipe, it is rather unimaginable that this fuel could be set on fire by exhaust gases of comparatively low temperature and holding little oxygen.

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THE DEVELOPMENT OF INCREASED EFFICIENCY IN STEAM APPLICATION FOR MARINE PURPOSES.

By Sir JAMES KEMNAL, F.R.S.E.,
Member of the Institution.

9th February, 1926.

INCREASED efficiency, both in land installations and on board ship, with increased economy in fuel, as well as the desire to make steam installations give the same calorific efficiency that is obtainable from the Diesel engine, is the origin of many improvements that have appeared in steam plant. These improvements are based mainly upon increases of pressure, feed temperature, and temperature of the superheat, and are restricted in the last case to the limit that the material, of which the superheaters are made, will stand.

The scientific foundation and advantages in connection with increased temperature and pressure have, of course, been known since the days of Carnot, Hirn, Rankine, and others. Many years ago Perkins built marine machinery to work at a steam pressure of 1,500 lbs. per square inch, but his attempts failed owing to the lack of mechanical facilities, and of the knowledge and machinery required for the construction of suitable boilers and engines.

The gain due to higher steam pressure arises partly from the fact that while the heat content per lb. of steam increases slightly up to 350 lbs. per square inch, it commences then to diminish slowly, and, therefore, as the pressure is increased above 350 lbs., no more heat, but theoretically slightly less, has to be transferred from the fuel to the water

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at the increased pressure. Consequently, with suitable arrangements of the turbine, greater utilisation of the steam can be obtained from the fuel at the higher pressures. The reduction in heat content, with increased pressure, has been established by several experimenters, notably by Mollier, Stodola, and Callendar, and Fig. 1, giving the variation in heat content per lb. of steam between pressures of 200 and 800 lbs. per square inch from a feed temperature of 32 degrees F., has been constructed on the Stodola basis.

It should be observed at the outset that the efficiency of the boilers is not materially modified, but changes in design and construction have been made to enable higher pressures to be used, with which, per unit of steam, more work can be done by the machine. It is only in comparatively recent times that the construction of steam generators, suitable for these high pressures, has been studied and become practicable, and the results obtained have been entirely from land installations. The development of the application of high pressures has taken place in two directions:—

1. In utilising pressures of 600 or 700 lbs. per square inch in new turbines which exhaust at pressures of from 250 to 350 lbs., and using this exhaust steam in existing plants.
2. In specially constructing turbines to utilise high pressure throughout the whole range, by increasing the stages of expansion in the one machine and reheating.

Of the former, the most prominent installation is at the Société D'Électricité de Flanders Langerbrugge Power Station, working at a pressure of 56 atmospheres (800 lbs. per square inch). At this station the anticipated results have already been achieved, and it is expected that eventually a thermal efficiency of from 28 to 30 per cent. will be realised. This is not far, if at all, short of what is obtained with the Diesel

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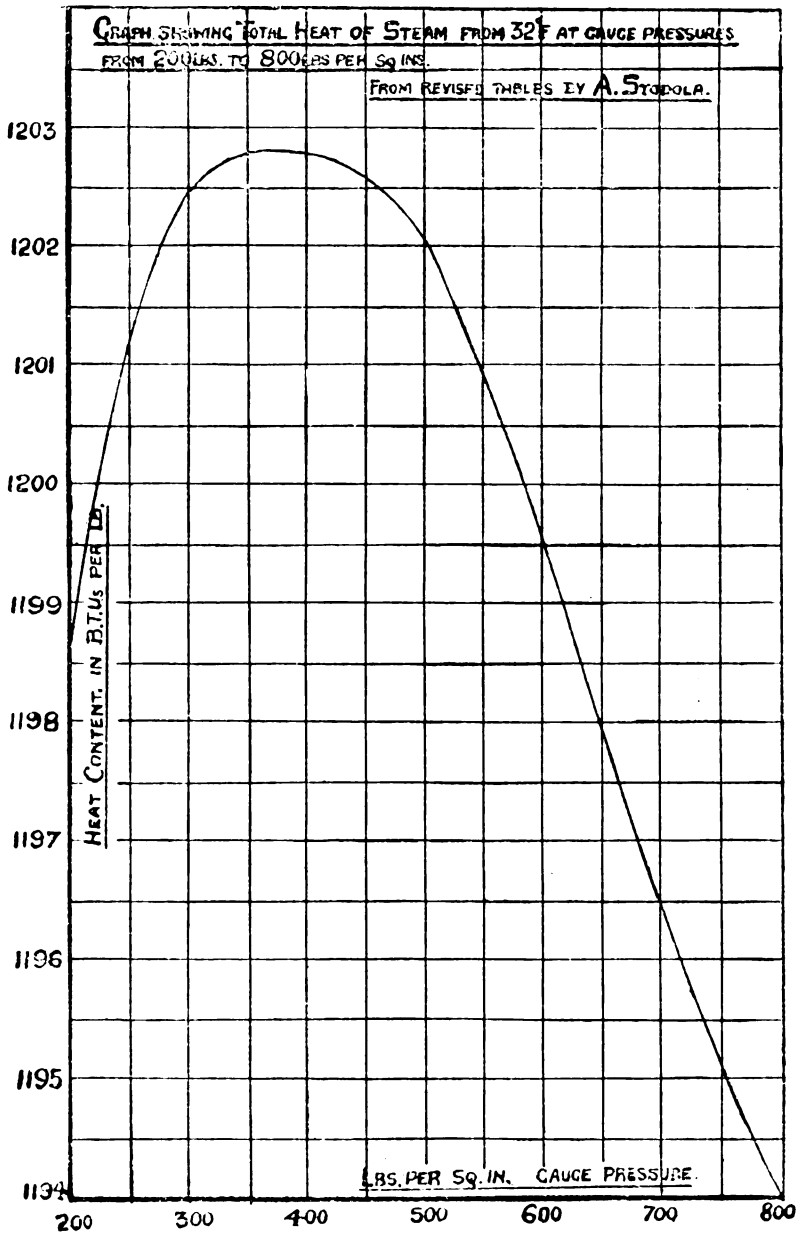

Fig. 1.

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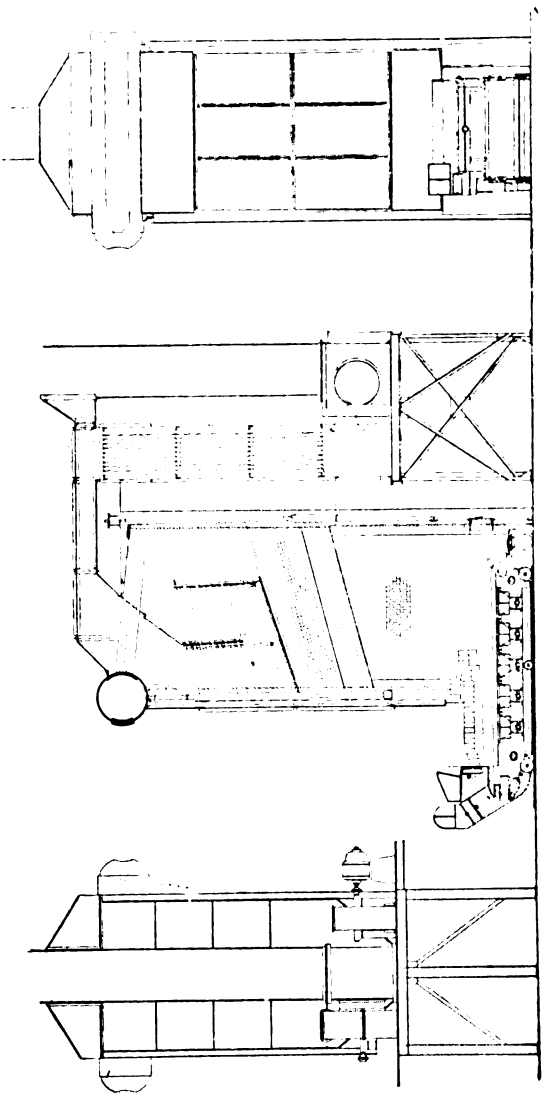

Fig. 2.—Normal Boiler, Langerbrügge Power Station.

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engine, and has this advantage, that a very much cheaper fuel, oil or coal, can be used for generating steam.

Of installations of the second category referred to, the Philo Station of the Ohio Power Co. and the Crawford Avenue Station of the Commonwealth Edison Co. are the most promising practical examples. Each has a working steam pressure of 650 lbs. per square inch, and a temperature of 750 degrees F. There are many other installations in America which will shortly prove striking examples of the increased economy due to high pressure. Notable amongst these are the following:—

Installations.	Working Pressure. Lbs.
The Edison Electric Illuminating Co., Weymouth, Boston	1,200
Twin Branch Power Co., Mishawaka	650
Columbia Power Co., Cincinatti, Ohio	650
U.S. Navy, Brooklyn and Bremerton	650
American Gas and Electric Co., Stanton Station	730

For some time boilers have also been constructed to work at from 500 to 1,250 lbs. steam pressure, mainly for testing valves, etc., notably at the Hancock Inspirator Works, the Consolidated Safety Valve Works, and Babcock & Wilcox's Works at Dumbarton.

In the trials carried out at the Philo Power Station, one kilowatt was generated at an expenditure of between 13,000 and 14,000 B.Th.U's., which, converted into shaft horse-power for marine purposes, would be under 10,000 B.Th.U's., corresponding to a thermal efficiency of about 25 per cent.

In all these installations, Babcock & Wilcox boilers, superheaters, economisers, and reheaters are used, this type of boiler being the only one adopted on a commercial scale, and with which definite results are recorded. At present there are no large installations in England working at these high pressures, excepting the forerunner, which was designed by

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Merz & McLellan for the North Tees Power Station of the Newcastle-upon-Tyne Electric Supply Co., where for five years

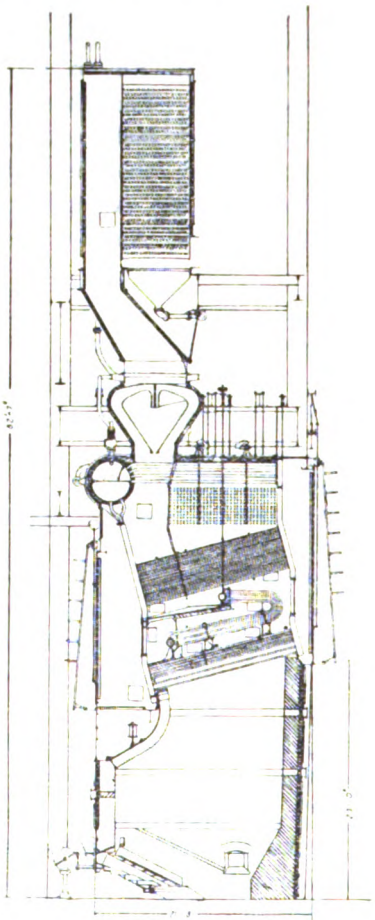

Fig. 3.—Boiler at the Weymouth Power Station of the Edison Electric Illuminating Co., Weymouth, Boston.

ten boilers have been working at 500 lbs. pressure, and quite recently other eight boilers have been installed, and are now in use. I have seen no records from this installation, but it

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is understood that the gain in economy, due to the higher boiler pressure, is from 4½ to 5 per cent., exclusive of the gain due to reheating and bleeding for feed-water heating.

In Germany the question of high pressures has been taken up with avidity. Over 100 boilers, having an aggregate heating surface of 68,000 square metres and of varying designs, are at present being constructed. There is also an interesting installation being carried out by Babcock & Wilcox at the Electric Power Station at Amsterdam, where the boilers are intended to work at 620 lbs. pressure, with a superheat temperature of 710 degrees F., and to supply 154,000 lbs. of steam per hour to a new turbine which exhausts at a steam pressure of 230 lbs. This exhaust steam is resuperheated in the reheater integral with the boiler to 710 degrees F., and is then conveyed to the original low-pressure turbines. This arrangement is very similar to that of the Flanders installation, excepting that in the latter there is no reheating, but a high initial degree of superheat of 840 degrees F. Under this temperature, durability is at least an open question. The Amsterdam boilers are fitted with appliances for burning pulverised fuel, the installation of which was also carried out by the boilermakers.

Several other plants might be mentioned which also have reheaters, notably the Philo and Crawford Avenue plants, the North Tees plant, and a station working at 400 lbs. pressure at Barking, designed by Merz & McLellan for the County of London Electric Supply Co.

In order to deal more effectively with the high temperature to which the steam is superheated, the superheaters are placed nearer the furnace zone than formerly. Nevertheless, the material at the present time on the market, from which superheater tubes can be made, places the probable limit of working temperature at about 750 degrees F.

Recently the question of adopting high pressure in marine work has come to the front, and a Clyde steamer, at present

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being built in Dumbarton for the Turbine Steam Navigation Co., will be fitted with high-pressure boilers and turbines for

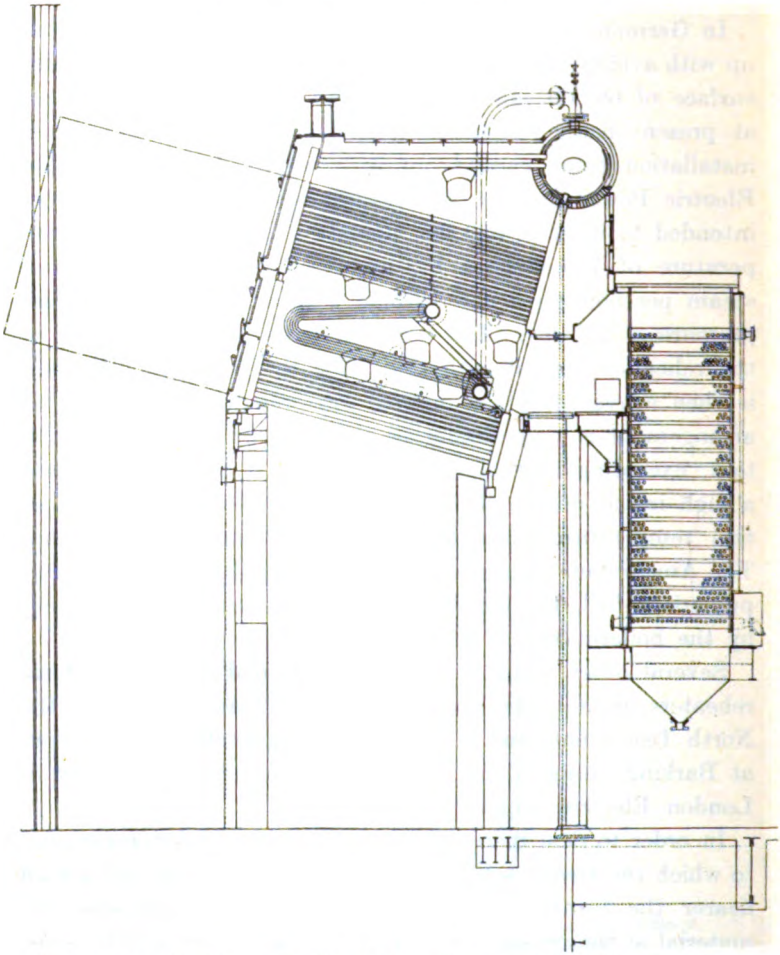

Fig. 4.—Normal Boiler at the Philo Power Station of the Ohio Power Co.

a working pressure of 500 lbs. per square inch. The boilers, in which lightness of weight and low first cost were the main considerations, are being constructed by Messrs. Yarrow & Co.,

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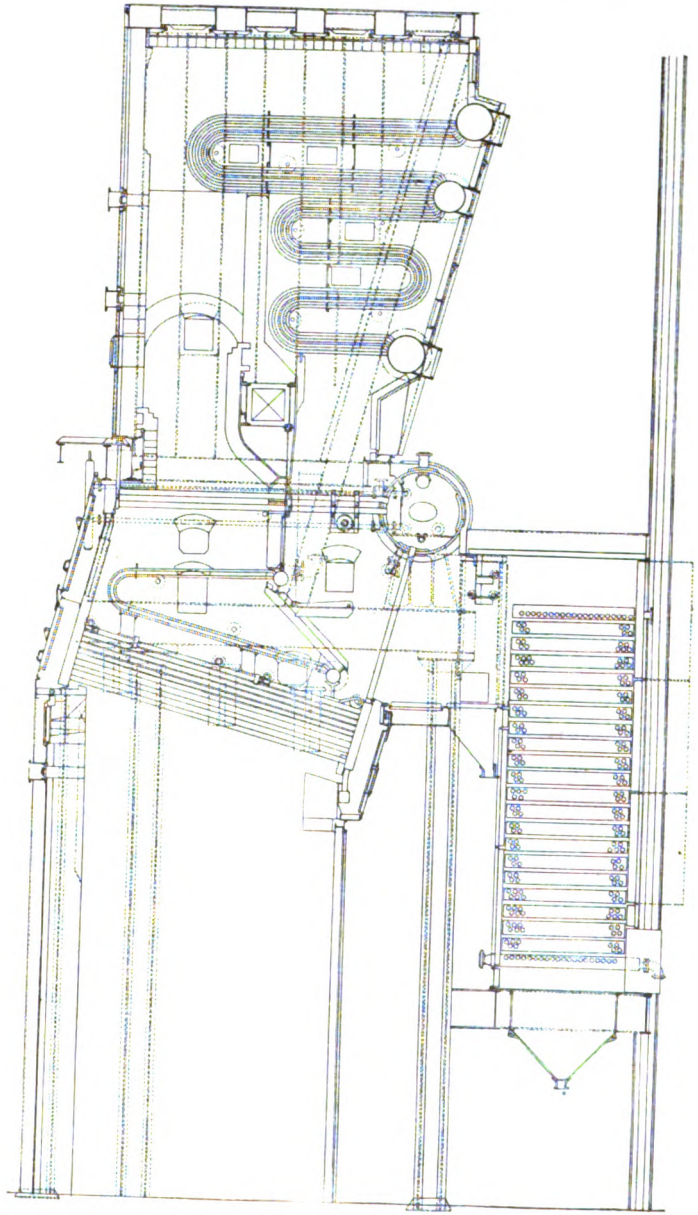

Fig. 5.—Reheater Boiler at the Philo Power Station of the Ohio Power Co.

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and the results obtained from this innovation will be followed by marine engineers with great interest. In this case, in order to help the boilers, the condenser of the main engines is being made in two sections, so that one section can always be in use while the other is under repair. The boilers approximate more closely to the type fitted in destroyers, which is perhaps not the most suitable for general mercantile work.

Sir Charles Parsons asserts that with high pressure and superheat, turbine installations can undoubtedly be carried out in a practical manner to give the same thermal efficiency as the Diesel engine, and with lower running costs. The sectional design of the Babcock & Wilcox boiler has proved itself exceptionally adaptable for high pressures, and boilers of this design have recently been put forward for pressures of 1,500 lbs. per square inch. The trials at the Edison Illuminating Station, Weymouth, with a pressure of 1,200 lbs., are awaited with great interest. In these high-pressure installations, the greatest care is required in the design of and materials for boiler mountings, such as water gauges, safety valves, stop valves, etc., for on these fittings the success of high pressures largely depends.

As riveted steam drums require exceptional care in manufacture, solid-drawn steam drums have been preferred for pressures of 600 lbs. and upwards. Although the Langerbrugge drums have been made riveted, and have proved to be quite satisfactory at 800 lbs. pressure, the care necessary in their construction made them almost as costly as solid-drawn drums.

Assuming a fuel value of 18,500 B.Th.U's. and 25 per cent. thermal efficiency, with oil-fired boilers and oil at £3 5s. per ton, the cost of fuel for producing 1,000 s.h.p. is about 193 pence, and compared with 30 per cent. thermal efficiency, and oil suitable for a Diesel engine at, say, £4 per ton, the cost of the latter will be 196 pence. The saving in fuel cost per s.h.p. in the boiler installation, with high pressure and

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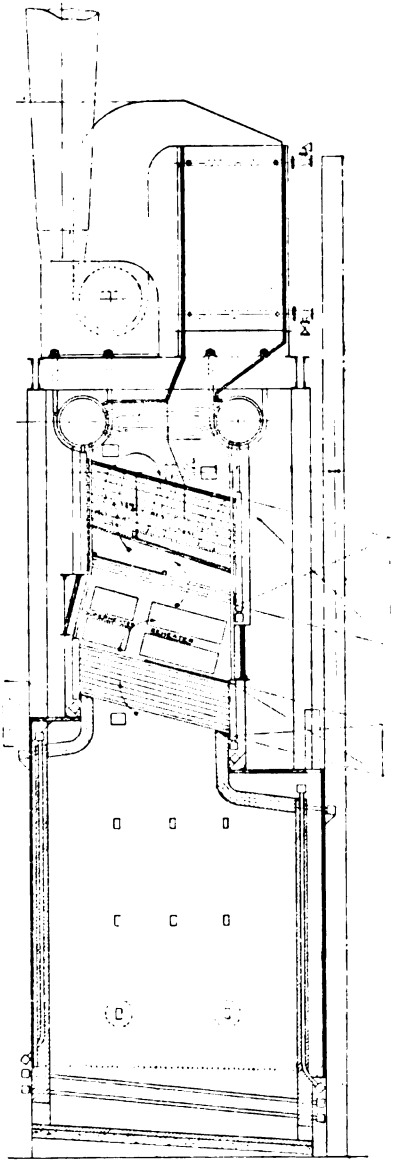

Fig. 6.—Combination Reheater Boiler at the Power Station of the Amsterdam Municipality.

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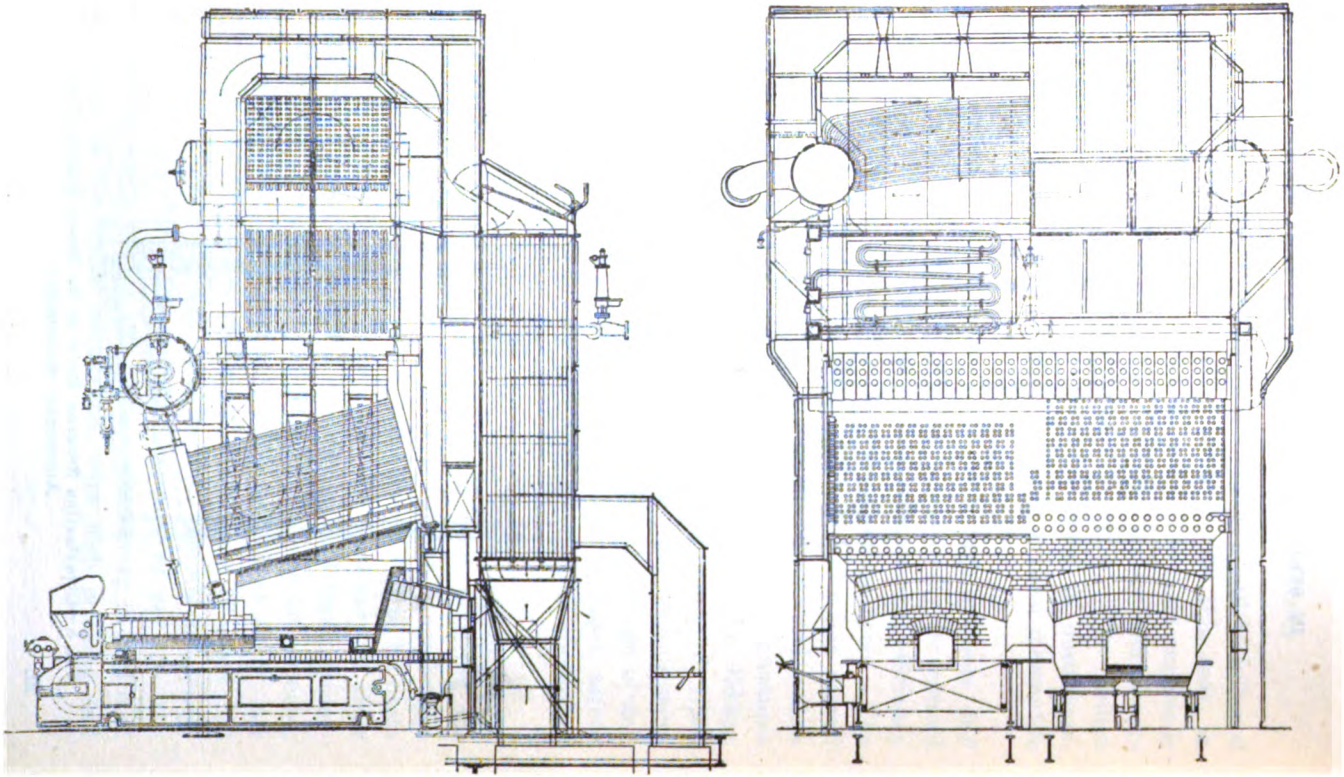

Fig. 7.—Reheater Boiler at the Power Station of the Newcastle Electric Supply Co.

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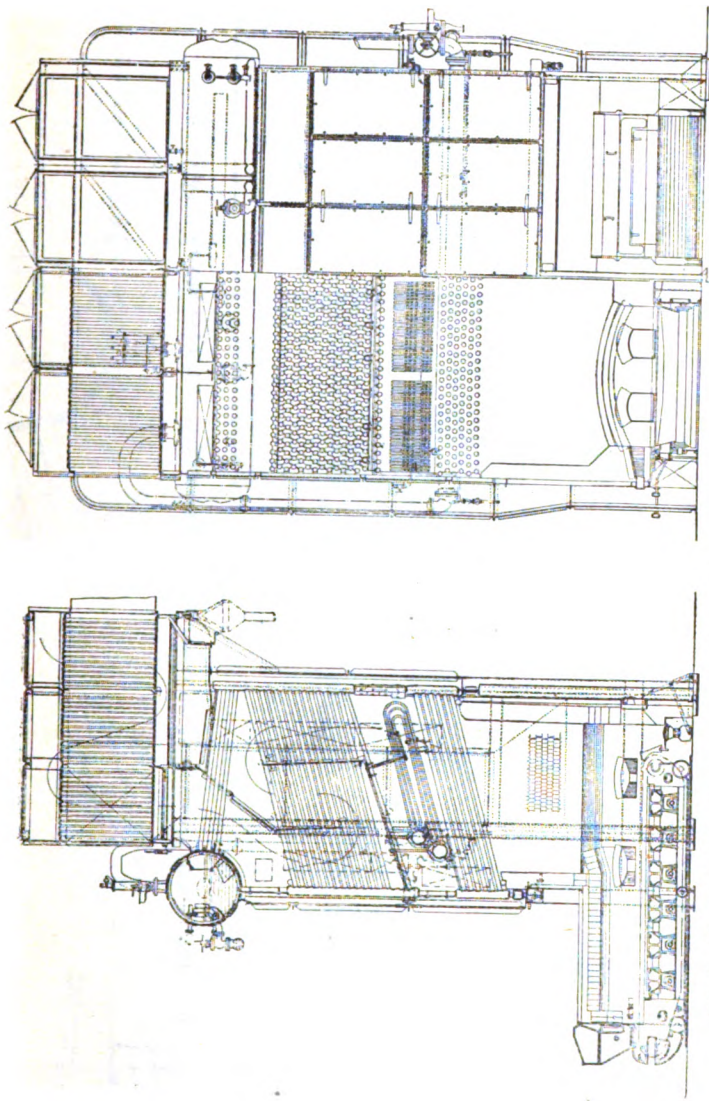

Fig. 8.—Normal Boiler at the Power Station of the County of London Electric Supply Co., Barking.

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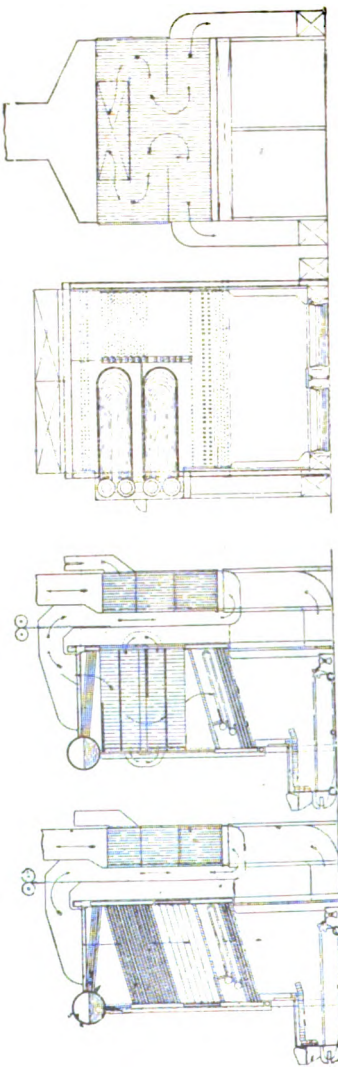

Fig. 9.—Reheater Boiler at the Power Station of the County of London Electric Supply Co.

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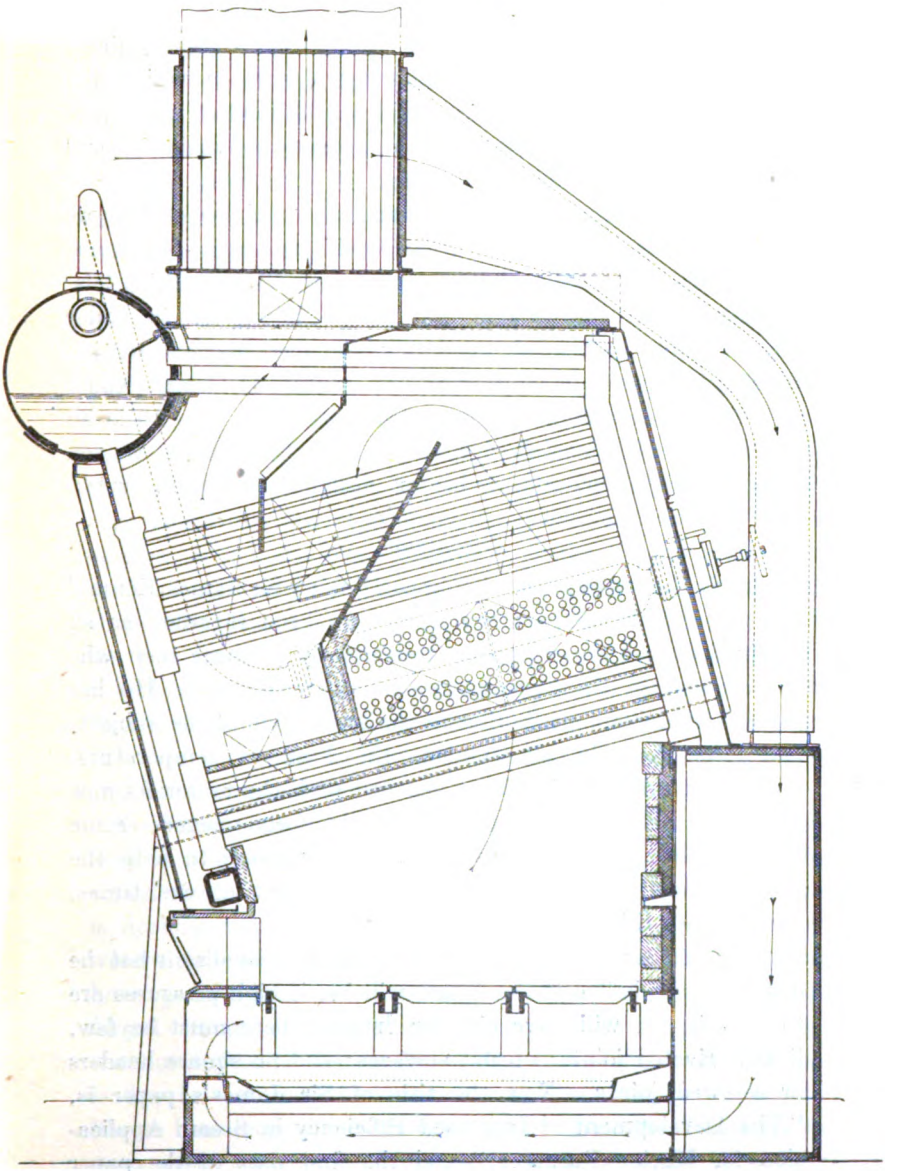

Fig. 10.—Coal-Fired High-Pressure Boiler for Marine Work.

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superheat, may even be anticipated to be about 2 per cent. compared with the fuel cost per s.h.p. with Diesel engines, and I have no doubt that sea-going plants, in which the advantages of the steam-engine will be obtained at no greater expenditure for fuel and much greater convenience and elasticity, will soon become general.

With coal burning, the comparison would be still more favourable, and the cost of fuel would be about 143 pence per 1,000 s.h.p., with coal at 25s. per ton and 11,000 B.Th.U's. heating value, and this allows for the falling off in boiler efficiency due to hand firing, but in the most modern marine installations mechanical stokers are introduced, which would still further considerably reduce the fuel cost. Fig. 10 is an illustration of a coal-fired high-pressure Babcock & Wilcox boiler, superheater, and air heater, designed for marine work.

Discussion.

Mr. S. T. CRUSH: Our thanks are due to Sir James Kemnal for this valuable paper; he has always been regarded as an inspiration and an example, especially by younger men who are engaged in the manufacture of steam boilers. He has made a valuable contribution to the knowledge of the subject, and says that, in his opinion, the limit of temperature, but not of pressure, has been reached with the materials now available. His statement is a call to forge-masters—some of them are here to-night—and to steel-makers to help the boilermaking industry to keep itself abreast of the times, and to keep this old country to the front.

From his remarks, it is not difficult to visualise what he considers the boiler of the future will be, if high pressures are to prevail. It will have circular drums; there must be few, if any, riveted joints; no flat surfaces; and no square headers or screwed joints. Now the title of Sir James's paper is, "The Development of Increased Efficiency in Steam Application for Marine Purposes," and the first part of the paper

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contains valuable information relating mainly to land boilers in America, a country which suffered no arrested engineering development during the war. On page 502, Sir James comes to grips with his subject. He refers to an installation being made by a firm on the Clyde for which the working pressure will be 500 lbs. per square inch. I am in a position to confirm that. He goes on to state that this installation, which he apparently views with concern and a sort of paternal interest—that sort of interest with which the credentials and achievements of a prospective son-in-law are examined—will have two condensers to help the boilers, or a condenser made in two sections. It would have been equally pertinent to remark that there will also be two funnels. But these boilers will not need "help" from the condensers, and the installation to which he refers will certainly approximate very closely to the type fitted in destroyers, which, in his opinion, is not the most suitable type for general mercantile work. Apparently Sir Charles Parsons thought otherwise, and those who designed the great German Atlantic liners which are still running, and have done good service, thought otherwise too. On the River Yangtze there is a large number of vessels fitted for general mercantile work with similar boilers; they are operating far from their base, carrying merchandise and doing splendid work.

Sir James now brings us to the details of the drums, and here it is interesting to observe that he speaks of solid-drawn steam drums. There is nothing new under the sun, and there is nothing new in solid-drawn steam drums. In 1910 they were fitted in H.M.S. "Attack." But since that day we have gone a little further, and reached the stage of solid-forged steam drums—drums which consist of one forging, without a rivet in the structure—and that is an advance which is due to the great forge-masters of this country. I should like to hear more about those drums of which Sir James states such great care was necessary in making them that they

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Mr. S. T. Crush.
were almost as costly as solid-drawn drums. It seems impossible to conceive of built-up drums being made in such an expensive way as to cost almost as much as solid-drawn drums. All that Sir James has communicated on this subject is appreciated, and no doubt it will be found useful in the days to come.

In conclusion, I should like to mention the name of one who contributed to the knowledge of raising steam for marine purposes in water-tube boilers. I refer to the late Mr. Andrew Foster, who passed away last week. By his genius and enterprise he added materially to our knowledge, and he will be missed by a large circle of friends.

Mr. James G. Weir, C.M.G., C.B.E. (Member of Council): Sir James Kemnal has chosen a subject which must appeal very strongly to the members of this Institution, of whom the majority are naturally pro-steam. The steam-engine for marine propulsion purposes is certainly on its trial, and it must be admitted that, unless definite increases in efficiency are achieved, it will almost certainly be superseded by the internal-combustion engine. Sir James has shown that there is a good deal of life in the old dog yet. He has given a very impressive catalogue of land installations, from which it may be accepted as proven that for land purposes high pressures are no longer experimental, but are a definite commercial proposition, and are, in fact, standard modern practice.

I should like, however, to mention some difficulties with regard to the application of such high pressures to marine conditions. The points I should like to go over are not particularly associated with the boiler itself, for which land practice will largely give a precedent, but with certain very vital troubles associated with the application of these pressures to marine conditions. I think the outstanding trouble which has to be dealt with is the question of the possible contamina-

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Mr. James G. Weir, C.M.G., C.B.E.

tion of feed-water. I have had the privilege of discussing with a number of marine engineers the general layout of high-pressure installations, and finally they have come to the conclusion that the feed circuit offers one of the most difficult problems. It is, I think, well established, that high-pressure boilers will not run satisfactorily except they have absolutely pure feed-water. Naval practice over a large number of years has consistently shown that engine-room trouble of all kinds is generally traceable to impure feed-water.

The prevention of contamination at sea can be adequately carried out at every stage in the process with the exception of the condenser; the condenser is the weak link in the chain. That is, of course, well understood, and for many years a very strong committee has been engaged in research on condenser corrosion, but they have not yet reached a direct solution. Now, my opinion is that to solve this problem a departure must be made from the ordinary materials, which are more or less susceptible to sea-water corrosion, and turn to other materials which are practically immune. Of these nickel, or at any rate a high nickel alloy, seems to be the only available solution. Tubes of monel metal, which is practically a 70 per cent. nickel alloy, have now been running for over two years in service conditions at sea, and it has been proved that they are entirely resistant to the action of sea-water. Tubes of this material are now commercially obtainable, and Messrs. Denny Bros'. high-pressure job will have one of the condensers fitted with this type of tube. This installation has not less than four condensers, showing the difficulty and the importance of the condenser question. Referring to Mr. Crush's remarks, a condenser will help a boiler if it can keep salt water out of the boiler; that is the reason why there are four condensers, so that one or other of them can be shut off should there be trouble.

There is another point that comes into prominence with high-pressure installations; as the pressure increases, and as

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Mr. James G. Weir, C.M.G., C.B.E.
the heat datum or temperature of the boiler rises, then the rejected heat also rises in quantity, and the problem occurs as to what is to be done with this. In land installations the universal practice has been hitherto to use economisers, but with rising pressures and the availability of bled steam for feed-heating which gives full economy, coupled with the practical disadvantages of high-pressure economisers, this type of apparatus is going out of favour in high-pressure land installations. Its place is being taken most frequently by air preheating, and this, of course, is the direct solution, and a solution which is making, I think, considerable headway for marine purposes.

There is, however, a third method which is possible, and I think practicable, and that is the use of a waste-heat boiler at low temperature. An examination of the possibilities of this system appears on paper to be quite satisfactory, and several proposals are under consideration just now—not for marine installations, but for land installations—whereby the overflow heat from high pressure will be absorbed by a low-pressure boiler. There are a number of subsidiary advantages for ship installations, one of which is that a closed de-aerated feed system is very easily and simply achieved, which is of considerable importance where a distilled and pure feed make-up is used, which makes no scale; no scale means active corrosion except where there is no oxygen content in the feed-water. I mention this third solution as, somehow or other, with high pressures for marine installations, marine engineers will have to tackle this question of rejected flue-gas heat, which is commonly neglected, and can easily be neglected on a moderate-pressure job.

Mr. Donald MacNicoll (Member): During the past few years marine engineers have witnessed a great increase in the application of internal-combustion engines to ship propulsion, and I believe that they will shortly see a steady development

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with respect to the adoption of higher steam pressures for steamships. Unquestionably "competition is an impulse to success," and when the economy of high steam pressures is established the competition between Diesel and steam engines will be watched with unusual interest.

Sir James Kemnal states in paragraph three "that while the heat content per lb. of steam increases slightly up to 350 lbs. per square inch, it commences then to diminish slowly, and, thereafter, as the pressure is increased above 350 lbs., no more heat, but theoretically slightly less, has to be transferred from the fuel to the water at the increased pressure." This is a most interesting statement to me, because it appears to corroborate a suggestion I made some years ago to a friend of mine who is engaged on the design of fire-tube and water-tube boilers in one of the foremost marine engineering concerns in this country. I put this question to him: "If you were asked to design a boiler for 500 lbs. pressure, what difference would you make in fire grate area and heating surface compared with one for 250 lbs. pressure?" He said, "I don't know. What would you do?" I suggested that the fire grate and heating surface should be made to suit the output of steam at 250 lbs. pressure, but that the boiler should be capable of withstanding 500 lbs. pressure, and when running the boiler stop valves should simply be closed down until a pressure of 500 lbs. was reached in the boiler. This, of course, is apart from the question of superheat. I should like to know if Sir James is in agreement with me.

He suggests that, in the meantime, 750 degrees F. is as high a temperature as is desirable with the material of the superheater tubes, and, from personal experience, I quite agree with him. In all new developments there is a tendency, quite natural of course, to make everything fool-proof, or at least to provide for every conceivable contingency. I think there is too great a tendency in this direction. Risks must

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Mr. Donald MacNicoll.
be taken, and surely with all the supereducation now available, and indeed largely embraced, more intelligence should be expected from the parties who run these installations. This endeavour to make everything fool-proof may considerably increase the first cost in new plants, and unfortunately first cost, I think not wisely, is to-day the ruling feature in the engineering and shipbuilding industries.

In the course of his paper, Sir James states that in the Langerbrugge installation the efficiency aimed at has been achieved. This must be most gratifying to all steam engineers, and is a most happy augury, I hope, for the experiment that will be tried this summer on the Clyde. In the year 1812 the first practical steam-boat "Comet" commenced plying on our historic river. In 1901 the first commercial turbine steamer "King Edward" was put into service. This year again the first marine supersteam turbine-vessel, "New King Edward," will commence her activities, and continue the series of notable achievements; like the "Comet" of 1812 and her marine namesake, I hope she will have a very long tail.

Mr. CRAWFORD W. HUME (Member): All engineers connected with the manufacture and operation of steam machinery will welcome Sir James Kemnal's very interesting paper. This is especially the case at the moment when the opinion of the press throughout the country, and particularly that of our leading local newspaper, appears to be that the only efficient marine power plant is the Diesel engine. From a perusal of the newspapers it appears that no intelligent shipowner would consider for a moment the installation of any kind of machinery except the Diesel engine, and that if the shipowner thinks of steam he at once classes himself as ridiculously out of date and quite unscientific.

Now Sir James, by his argument on page 504, shows that, although up till now the thermal efficiency of a steam

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plant such as he has in mind is not quite so high as that of a Diesel engine, nevertheless, the fuel cost per horse-power for the steam plant can be quite easily brought below that of the internal-combustion plant, in view of the fact that the former can use a very much cheaper grade of fuel than the latter. Also, I think, there is no doubt that, as a rule, the first cost of Diesel machinery is considerably higher than that of steam plant, while the maintenance cost too is generally conceded to be higher.

The question of efficiency, therefore, comes down in its commercial application, not so much to thermal efficiency as to what might be called "efficiency of capital invested," and I think this efficiency is higher in the properly chosen steam plant than in any other type of machinery.

With regard to the efficiency of steam boilers themselves, Sir James does not mention the advantages which accrue from preheating the air for combustion, especially in cases where bleeding of the turbines is resorted to for feed-heating, and it may be of interest to state that at least one of the American firms that he mentions is going in very extensively for preheating the air. That firm is the American Gas and Electric Co., which has placed six orders for Howden-Ljungström preheaters, the last of these orders covering 16 units, with an aggregate heating surface of 647,000 square feet. In this case the air preheaters are being fitted to six boilers and six steam reheaters at the Stanton Station to which Sir James refers. At the same time, the American Gas and Electric Co. have air preheaters of this type installed at the Philo Station and at the Atlantic City Station. These preheaters are supplying air at temperatures of from 350 to 390 degrees F., corresponding to flue-gas temperatures of from 400 to 520 degrees F. respectively, over the range of boiler rating from 100 to 300 per cent. as computed in the U.S.A. By the way, 100 per cent. boiler rating in the United States is equivalent to an evaporation "from and at" of 3·45 lbs. per square foot

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Mr. Crawford W. Hume.

of heating surface. For this same range of rating the coal savings at 12 per cent. CO_2 work out at 9½ per cent. at the low rating, to 11½ per cent at the 300 per cent. rating, while the temperature of the waste gases leaving the preheater varies from 180 to 270 degrees F.

Sir James mentions only the Babcock & Wilcox boiler and the Yarrow boiler, which are, of course, purely water-tube boilers, and as such are excellent, but I think that for marine purposes there still remains, whether rightly or wrongly, a prejudice in the minds of most superintendent engineers against water-tube boilers. To meet this prejudice my firm have had an experimental boiler built, and are now preparing to carry out tests on it. This boiler is built for what Sir James would probably consider a low pressure, namely, 315 lbs. per square inch, but there is no reason why the pressure should not be raised in similar boilers to 450 or 500 lbs. without any difficulty whatever.

This particular boiler consists of a cylindrical shell having five furnaces going straight through, Fig. 11. At the back of the cylindrical part, and between that and a water-tube element, a combustion chamber is formed by the space. The gases pass from that combustion chamber between the tubes of the water-tube element, and thence to an air preheater. There is a lane between the tubes to allow a portion of the gases to pass through to a superheater disposed behind the water-tube element, and the arrangement is such that the superheat may be regulated by the operation of a damper controlling the amount of gases passing through the superheater. This boiler is the outcome of tests carried out on a marine boiler with highly preheated air, in which it was found that from 70 to 80 per cent. of the evaporation took place in the furnaces.

The boiler, I think, has all the advantages of both the cylindrical boiler and the water-tube boiler, with the disadvantages of neither. For instance, the common fault of the

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ordinary cylindrical boiler is that the circulation is anything but definite; in this case, however, the water at the bottom of the cylindrical part is drawn away by pipes connecting it to the bottom of the water-tube element. Also, the temperature of the gases in contact with the water tubes is in the neighbourhood of 1,600 degrees F., so that difficulties such

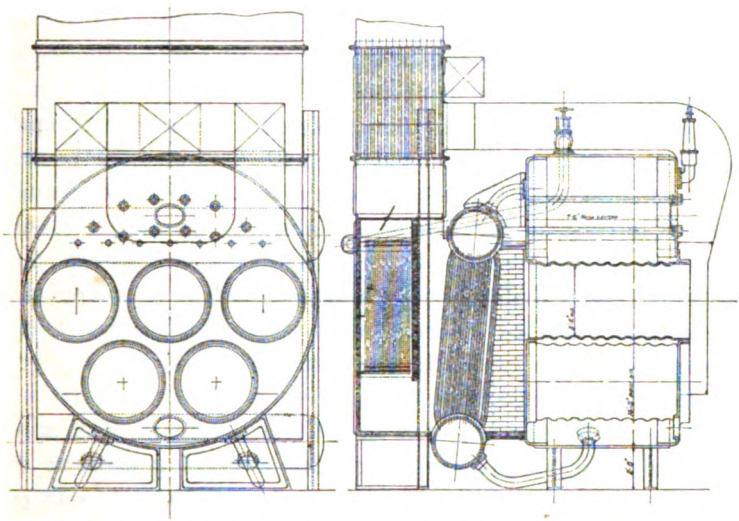

Fig. 11.—Howden High-Pressure Cylindrical Boiler.

as are often experienced with the tubes of water-tube boilers, subjected as they are to temperatures 1,000 degrees higher than this, cannot take place.

The weight of the boiler, as compared to a Scotch boiler of the same output, is about 40 per cent. less. The boiler is adaptable for oil or coal firing, either by hand or by mechanical means. The difficulty of disposing of the ash, which renders it almost impossible to apply mechanical stoking to cylindrical boilers in which the ash must be removed at the front of the boiler, is successfully overcome in this new type of boiler, as the ashes are removed through the

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Mr. Crawford W. Hume.
bottom of the combustion chamber and carried away by mechanical means.

In conclusion, I wish to thank Sir James for his paper, which forms a valuable contribution to the data of steam engineering, and will further strengthen the position of those who contend that steam plant can be, and is being, developed so as to be the most efficient means of producing power commercially.

Mr. W. W. Marriner (Member of Council): From investigations made in the United States and Germany, I can confirm the information which Sir James Kemnal gives in his paper concerning what has been achieved with high-pressure boilers in these countries. There is no doubt that in the near future further interesting developments in high-pressure boilers will be seen. One interesting boiler of this type, which was not mentioned by Sir James, is the Atmos boiler, in which the elements are rotated. I saw one of these at work, but as to whether it will be on the line of future progress, it is not yet possible to give an opinion.

Sir James makes reference to a Clyde steamer which is to be fitted with two Yarrow boilers for a working pressure of 500 lbs. per square inch, and it is very satisfactory to know that this type of boiler was chosen after the most careful consideration of all other types. The boilers chosen have the following advantages:—

1. The small number of joints which have to be broken and remade when examining the boiler.
2. The large proportion of heating surface which is exposed to radiation.
3. No chambers exposed to pressure other than circular ones.

In connection with this last consideration, it is evident that the square or rectangular form of header has a tendency to get out of shape when exposed to very high pressures, and sooner or later will give trouble.

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With reference to the Barking station mentioned in the paper, one-half of the boilers and reheaters are of the Yarrow type, and they are giving every satisfaction at both the pressure and superheat which are stipulated, after having been on load for 12 months.

I am very interested to see the arrangement which Sir James proposes for a marine automatic stoker, because it is very important that every effort be made by engineers in this country to show the superiority of coal over oil as the fuel for use on board ship. Coal is one of our greatest national assets, and we ought not to stand by and see coal being replaced by oil, which has to be brought from abroad, without making a great effort to retain its use. It is for this reason that particular interest is attached to the forthcoming trials of the Clyde steamer now being built by Messrs. Denny & Bros., and which is to be fitted with Parsons high-pressure turbines using superheated steam supplied from Yarrow boilers.

Mr. R. J. Butler (Member): From the curve plotted in Fig. 1 showing the heat content of steam at varying pressures, it will be seen that the difference according to the latest researches is 4 B.Th.U's. increase from 200 lbs. to 350 lbs. pressure, with a fall of $8\frac{3}{4}$ B.Th.U's. from 350 to 800 lbs. These variations in a total of 1,200 amount to one-third and three-quarters of one per cent., and it would, therefore, appear that the theoretical gain mentioned on page 495, obtained from the consideration of the latest figures, is scarcely appreciable over that based on the data taken from the usually accepted steam tables.

In the thermal efficiencies quoted for high-pressure stations of 25 to 30 per cent., is the power used for all purposes included, or is the figure the nett efficiency of the main steam-generating plant with its corresponding prime mover? Sir James quotes a figure of 10,000 B.Th.U's. per s.h.p. if the Philo power-station plant were applied to marine work. A

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Mr. R. J. Butler.
glance at Figs 4 and 5 will show how far off we are to realisation of the installation of such an equipment on board ship, and it would appear that, for a ship of any size having a battery of boilers, conveying the steam back for reheating in boilers specially fitted for the purpose is an impossibility.

With a normal pressure and temperature marine equipment without intensive air-preheating, 11,350 B.Th.U's. per s.h.p., or 22½ per cent. efficiency (exclusive of auxiliary plant), has been obtained recently on trial, and this figure can undoubtedly be improved after the *personnel* has settled down to regular operation.

Some years ago, when the Admiralty were fitting Belleville boilers with a pressure of 300 lbs. per square inch, a certain ship with which I was associated incurred enormous water losses, so much so that the evaporating plant had to be run continuously. The pipework was examined and found to be tight, and the reason for the loss was very puzzling, but was ultimately traced to invisible leakage through the junction-box doors. These were analogous to those fitted in Babcock & Wilcox boilers with seamless asbestos gaskets as joints. The Admiralty subsequently reduced the boiler pressures of ships, partly, I believe, for this reason, and it would be very interesting if Sir James would state how the difficulty with twice or more that boiler pressure is overcome. At sea, of course, this loss is of vital importance, irrespective of the serious wastage of fuel.

Another practical point is: What effect has the high temperatures and pressures, now aimed at, on the expanded joints of superheater tubes and boiler tubes? It might be imagined that these would become annealed and soft, and possibly tend to draw out or leak. A plant, however, in which I am interested has shown, even with the moderate temperature of 600 degrees F., that the superheater tubes become hard and brittle after being some time in commission. I believe this experience is common. Can Sir James thrown any light

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on this matter? As pointed out, the mountings of the boiler will determine the success or otherwise of the high-pressure and temperature schemes. A fortnight ago I asked an eminent boilermaker on the Clyde what he proposed for his gauge glass mountings for some high-pressure boilers he was building. His reply was, "I should like to know," so that there are evidently some problems still to solve.

Mr. WILLIAM BROWN (Member): The President told us that he asked Sir James if he were making a final effort to bolster up steam before the Diesel engine entirely supplanted it, and that he received the reply "No." So far I agree with Sir James, and also one of the previous speakers who stated that the real steam era was just commencing. To me, the paper seems to be an effort to hold up the water-tube boiler as an essential part of the equipment in the development of high steam-pressures for marine purposes. I think it will be agreed that high steam-pressures are very desirable, and becoming more necessary every day. The reciprocating engine is gradually giving place to the steam turbine for driving electric generators and the propellers of ships, so the low- and medium-pressure steam generators must in turn give place to other and different types of steam generator.

Some weeks ago there appeared in the pages of "Power" an article illustrating and describing an entirely different method of generating extra high-pressure steam. The furnace described is oil-fired, and contains principally the superheater, while the products of combustion give up their heat to an economiser. The steam generator may be placed in any convenient position. Feed-water is pumped through the economiser coils on its way to the steam generator. A motor-driven pump takes saturated steam from the generator and forces it through the superheater coils, the superheated steam returning to the generator, where, mixing with the water, it generates more saturated steam, and so this circulation con-

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Mr. William Brown.
tinues until the desired pressure is obtained. Superheated steam is drawn from the pipe between the superheaters and the generator, and passes through many stages before it reaches the hot well, while the feed pump looks after the make-up required in the steam generator.

Pressures of 1,500 and 1,700 lbs. per square inch were obtained and used at a temperature of 900 degrees F. I admit that such an arrangement would not be economical for low or medium pressures, but it appears to be an excellent proposition for very high pressures. The absence of a furnace near the steam generator, its comparatively small size, and, therefore, thickness, makes it an inviting proposition. Applied to marine work, the generator may be placed anywhere, particularly low down, and the whole arrangement only occupies one-third of the space required by a Babcock & Wilcox boiler for the same capacity. That the arrangement is not a toy will be appreciated from the fact that a 1,000-kw. plant has been used with success, while an 18,000-kw. plant is in course of construction.

Sir James states that Messrs. Babcock & Wilcox have prepared designs for a boiler suitable for a pressure of 1,500 lbs. per square inch, and that a station supplied with Babcock & Wilcox high-pressure boilers is nearly completed in America, and, further, that great care is required in connection with the drum mountings. The making of the drums does not present very great difficulty, but the attachments do. Mr. Crush stated that the forge-masters had overcome the difficulty of making drums by forging, and that these were no longer solid drawn. I shall be glad to know if the ends are forged solid. I understand that in America the drums are 4 or 5 inches thick, and if Sir James will state how the various attachments are fixed and made steam-tight for a pressure of 1,200 lbs. per square inch and a temperature of 800 degrees F. I shall feel indebted to him. When a steam drum has to be as thick as 4 or 5 inches, the cost of manu-

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facture must be very great indeed, which tends to open the way to other methods for the generation of very high-pressure steam.

Mr. Robert Love (Member): In his paper Sir James Kemnal indicates one line in which advancement can be made towards obtaining increased efficiency in marine machinery. Unfortunately the boiler arrangements shown and described are for land installations, and would require considerable modification before they were applicable to marine work. It has been found in Diesel engine practice that although an engine may prove satisfactory in a land installation, the same engine may be quite unsuited for marine purposes. On the other hand, an engine which proves satisfactory in marine work will, generally speaking, be also quite suitable for land work. The same conditions will, I think, hold in the case of the high-pressure steam installation. The high steam-pressures obtained by Sir James, combined with high superheat temperatures, will necessitate a very superior class of workmanship, the use of special materials, and most careful attention in service. During manœuvring, rapidly changing temperature conditions, combined with a variable demand on boiler output, present conditions not met with in land installations. In the paper reference is made to an assertion by Sir Charles Parsons that, with high pressure and superheat, turbine installations can undoubtedly be carried out in a practical manner to give the same thermal efficiency as the Diesel engine with lower running costs. Comparative figures for steam and Diesel machinery follow, but the method of presenting these figures does not appeal to the engineer who has been used to consider fuel consumption per s.h.p. or b.h.p. per hour. By converting the figures given to this basis, it is found that, for the turbine installation with oil-fired high-pressure boilers, the consumption is ·555 lb. per s.h.p. per hour; for the Diesel installation, ·457 lb. per s.h.p.

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Mr. Robert Love.

per hour; and for the turbine installation with coal-fired high-pressure boilers, 1·07 lb. per s.h.p. per hour, all for propelling machinery only.

Diesel engines are in service to-day giving continuously from 10 to 15 per cent. better fuel consumption than that stated above, but no marine turbine installation has yet, so far as I am aware, been put into service giving fuel consumptions as quoted in the paper. Further, when the fuel consumption for all purposes is considered, the Diesel engine installation shows a still greater saving.

Mr. Norman C. Bridge: The first thing I learned from the paper was that the temperature limit was determined by the material of which the superheaters are made. Up till then I had been under the impression that it was the materials of which the valves and the mechanisms for controlling the steam were made which limited the temperature. Like the speaker who opened the discussion, I was a little puzzled as to how the splitting of the condenser into two sections would help the boilers. Dividing condensers is now becoming common practice in land installations, to enable the tubes to be cleaned without shutting down the main generating units, but I think Mr. Weir has explained the point raised by Sir James.

One of the drawbacks to steam plant for marine work is the large bulk required for the furnaces, etc., for these high-efficiency installations, but I think that there are some promising lines of development possible in this respect. Indeed one has already been mentioned, in which the dividing band between the fire and the water is made to move to enable greater evaporation to be obtained per unit of heating surface. That is carried out in the Atmos boiler with revolving tubes. It is new to me that without any radical change in boiler design pressures up to 1,500 lbs. per square inch can be used. Speaking from memory, I believe that such a pressure is

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somewhere near the region where the latent heat of steam disappears; that is to say, where no surface is required for the release of the steam bubbles from the water, and which implies that no steam drum is required. The absence of steam drums will not only bring down the weight of the steam installation, but will reduce the space occupied. Sir James' comparison of costs is very interesting, and it would be more so still if he had given a corresponding figure for the Diesel-oil-steam combination such as the "Still" engine. I am inclined to think that in the end the Still engine, or something of that sort, will finally settle the struggle between the steam-engine and the Diesel engine, so far as marine work is concerned.

Mr. C. R. H. Boxx (Associate Member): Sir James Kennal gives an excellent description of various high-pressure land installations, which are ample evidence of the increasing appreciation of the economies possible by the use of what may still be called exceptionally high pressures. There is, however, a considerable difference between land and marine conditions. The steam turbine is admirably suited for driving a dynamo, and that is why it has been able to compete successfully with the Diesel engine in electrical power-station work. It is not so well adapted for driving a propeller, and its economic use for this purpose requires a gear or its equivalent, which are undesirable complications. Conditions at sea are, to say the least of it, not conducive to the satisfactory working of a high-pressure installation. Due to the working of the ship, trouble might be expected in keeping the pipe joints tight at high pressures and temperatures; there would be the feed-water difficulty, and the accumulation of condenser troubles. This may be prejudice on my part, and I look forward to the results of Messrs. Denny's most interesting adventure.

Sir James' paper is largely concerned with the efficiency of

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the high steam-pressure installation as compared with that of the Diesel engine. To this extent, it is a special plea for the consideration of the possibilities of the steam-engine, and as such takes its place beside the paper read by Sir John Biles before the Institution of Naval Architects last year. The Diesel engine is by no means perfect, but what it does easily the steam plant can only achieve with many refinements and under specially favourable conditions. Nevertheless, it is remarkable that not one of the improved types of prime mover which have been introduced has proved definitely to be, in all respects, superior to the original steam-engine. There has been a period of specialisation rather than one of significant advance, and engineers concerned may be left to compete with each other as to the particular type best suited to a special purpose; while they struggle, some new development will probably take place.

It may be taken, I think, that when over-refinement becomes necessary in order to adapt a machine to its purpose, there is something wrong in the application of fundamental principles. In the struggle for decided superiority, all the prime movers are becoming over-refined. The bugbear of them all is that heat energy, or more properly, chemical energy, is converted into mechanical energy by means of a pressure fluid. Prof. Thurston has calculated that a plain tubular boiler, 60 inches in diameter by 15 feet long, containing 66 3-inch tubes with 850 square feet of heating surface and 30 square feet of grate area, weighing 9,500 lbs., and containing almost the same weight of water, will have only 21 lbs. of steam at 75 lbs. gauge pressure. Under these conditions it stores 52,000,000 foot-pounds of energy, of which only 4 per cent. is in the steam, but this energy is enough to force the boiler just about one mile into the air, with an initial velocity of nearly 600 feet per second. If that is so, what would happen if a boiler under 750 lbs. gauge pressure exploded? When the temperature approaches 700 degrees F. it is in a very dangerous region,

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and no matter how carefully the materials might be selected, they would be liable to progressive failure, slow maybe, but, nevertheless, ending in catastrophe.

There are at least two other methods of converting chemical energy into mechanical energy without the medium of a pressure fluid. One is by means of a thermo-electric generator, and the other is by consuming the fuel in an electric cell. I can speak of the first method from practical experience, as I have been engaged for some time developing such a generator. It may be contended that neither of these methods is of practical importance, but the following figures show that the results now obtained entitle it to consideration:—

	Total Weight.
Marine steam installation with forced draught - - - - - -	450 lbs. per i.h.p.
Marine Diesel installation - - -	250 ,, ,, b.h.p.
Thermo-electric generator output -	1·3 lb. per watt = 1,000 lbs. per h.p.

Such a generator can be run at 1,300 degrees F. with a possible thermal efficiency of 72 per cent., and a practical thermal efficiency of 64 per cent. It is absolutely self-contained, and can burn any kind of fuel in any way. The great trouble with such generators at present is the leakage of heat over and above that required to generate the power, but I am confident that this defect will soon be entirely overcome, while the weight per horse-power will be reduced to such a figure, taken in conjunction with the motor, that it will be far below any other type of installation.

The method of consuming the fuel in an electric cell has not yet assumed a practical aspect, but it is interesting to note that oxygen and hydrogen, combining to form one gram-molecule of water (18 grams), will give 194,000 coulombs at

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1·47 volt at 0 degrees C., that is, 285,000 watt-seconds, without the evolution of heat. Now 285,000 watt-seconds is equivalent to 68,000 gram-calories, exactly the amount of heat evolved in the combustion of oxygen and hydrogen to produce one gram-molecule of water. Therefore, the conversion is 100 per cent. efficient. This efficiency holds good for any electro-chemical reaction, and in practice an efficiency of 90 per cent. is easily obtained. Jablochkoff long ago invented a cell in which carbon plates were consumed, and since then little progress seems to have been made in this direction. However, these facts should be a welcome reminder to motive-power engineers of the extreme danger of taking too circumscribed a view of things, and a warning to them to make the best of it while they still have the field to themselves.

Mr. Kenneth Morrison (Associate Member): It is interesting to note that, from the many examples which Sir James Kennal gives of high-pressure boilers, the boilermaker's problem seems to have been solved by the adaptation of existing types. This, of course, is the common and natural process, but I am of opinion that to deal with these high pressures a new type of boiler will eventually be evolved. To me, the ideal type should have the following characteristics:—

1. Very small water content.
2. All pressure parts cylindrical, and not exceeding, say, 18 inches in diameter, so as to avoid the use of excessive thickness of material.
3. Minimum riveting of pressure parts.
4. Few, and preferably, no, joints or double thicknesses exposed to flame.
5. The parts so arranged that no flue dust or ashes could lodge on any pressure part exposed to flame.
6. Minimum of danger from expansion strains.
7. Perfect circulation without priming.

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Mr. Kenneth Morrison.

I admit that the internal inspection of such a boiler would be difficult, but the above conditions, if coupled with pure feed-water, would remove the principal causes of deterioration which render internal inspection so necessary. Conditions 1, 2, and 3 are imposed by pressure, and 4, 5, and 6 by temperature, No. 7 being desirable in any similar type of boiler. The whole of these conditions may be preferable in a boiler with any pressure, but they become more essential as temperature and stress reach the limiting conditions of the steel of which the boiler is constructed. It is perhaps difficult to form a mental picture of such a boiler, more especially if any degree of durability is expected of it, and while the installations referred to must be considered as exceptional in the meantime, I have no doubt that they represent a new and more economical type of steam plant which will be largely adopted in the future.

Eng.-Capt. W. Onyon, M.V.O., R.N. (Member of Council): In my opinion, the Yarrow type of water-tube boiler, in virtue of its design, is more fitted for mercantile work than any other type using a pressure of 500 lbs. per square inch or more, and if an internal separator of the very latest pattern is fitted there will be an absence of priming. There will be also less liability to overheating of tubes by the introduction of salt water than with any other type of boiler known. Even if a salt detector is fitted, and the condenser divided as is suggested by Sir Charles Parsons, priming will occur and damage will be done long before any steps can be taken by the engineer in charge to prevent it, unless some efficient form of separator is fitted.

A condenser tube, such as a monel or a super-nickel tube, must of necessity be adopted, and, in my opinion, no attempt should be made to use high-pressure steam in a ship, especially where any forcing is necessary, unless the precautions suggested above have been taken.

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Mr. Stanley S. Cook.

Mr. STANLEY S. COOK: Sir James Kemnal bases part of the case for higher steam pressures on the diminishing value of the total heat of the steam with increase of pressure, after a certain value of the pressure has been reached, and gives in Fig. 1 a curve, deduced from Stodola's revised tables, in which the total heat has its maximum value at a pressure of about 400 lbs. per square inch. Unfortunately, various experimenters do not agree on this point, and Callendar's values for the total heat of saturated steam are still increasing with the pressure up to about 1,500 lbs. per square inch. If, however, instead of saturation, a constant final temperature is assumed, an increase of pressure is then accompanied by a decrease in total heat at all values of the pressure, and at high pressures this decrease becomes fairly rapid. For example, at 700 degrees F. final temperature, the total heat, according to Callendar, is, for 500 lbs. per square inch, 1,362·7 units; and for 1,000 lbs. per square inch, 1,336·8 units.

The case for the use of high pressure rests, however, on higher ground than this, and is fortunately not dependent upon the value of the total heat determined by any particular experiment. It may, in fact, be said with certainty that if the higher of two experimental values for the total heat is the true one, then the amount available for conversion will also be higher, so that the effect of varying initial pressure upon thermal efficiency is practically independent of experimental constants. This follows from the fundamental laws of thermo-dynamics. The heat supplied during the process of evaporation is by far the largest part of the total heat absorbed by the steam. The efficiency of utilisation of any portion of heat received will be increased with the temperature of reception. By increasing the boiler pressure, therefore, the temperature of heat reception is increased, and also the thermal efficiency of the major part of the heat supplied.

The following table gives the relation between the available

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energy (adiabatic) and the heat supplied under the conditions named.

1. Pressure 200 lbs. saturated.
2. ,, 200 lbs. superheated to 700 degrees F.
3. ,, 500 lbs. saturated.
4. ,, 500 lbs. superheated to 700 degrees F.
5. ,, 1,000 lbs. ,, ,, ,, ,,
6. ,, 2,000 lbs. ,, ,, ,, ,,

On the assumption of a feed-water temperature of 200 degrees F. and a vacuum of 29 inches (Hg.).

Initial pressure, lbs. per square inch absolute -	200	200	500	500	1,000	2,000
Initial temperature, degrees F. - - -	382	700	468·6	700	700	700
Total heat, B.Th.U's. per lb. - - -	1,205·4	1,378·2	1,222·2	1,362·7	1,336·8	1,285·2
Heat supplied per lb., B.Th.U's. - - -	1,037·4	1,210·2	1,054·2	1,194·7	1,168·8	1,117·2
Vacuum, inches - -	29 (Hg.)	—	—	—	—	—
Available energy per lb., B.Th.U's. - - -	370·5	449·3	427·3	494·1	519·1	528·2
Thermal efficiency, per cent. - - - -	35·7	37·1	40·5	41·35	44·4	47·3

It will be seen from this table that increase of pressure leads to a considerable increase of thermal efficiency, in spite of the fact that the values of the total heat are taken from Callendar's tables, which, for saturated steam, do not show a similar decrease in value with increase of pressure to that given in Fig. 1 of Sir James Kemnal's paper.

Mr. Thomas B. Mackenzie (Member): As a steam-power engineer I am much interested in Sir James Kemnal's valuable paper, and have made the following calculations which fully confirm his thesis.

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Mr. Thomas B. Mackenzie.

Let a turbine drive be divided into two, a high- and a low-pressure unit, the exhaust from the H.P. being reheated before going to the L.P. turbine. Let the initial pressure in the H.P. turbine be 500 lbs. per square inch absolute, superheated to 750 degrees F. The total heat (from Prof. Callendar's Steam Tables) is 1,390·1 B.Th.U's., and the entropy is 1·6401 ranks. Let this be expanded adiabatically to a terminal pressure of 72 lbs. per square inch absolute.

		H	ϕ
72 lbs. absolute	at 320 degrees F. -	1,192·6	1·6445
	at 310 degrees F. -	1,187·2	1·6375

Interpolating at $\phi = 1{\cdot}6401$, $H_\phi = 1{,}189{\cdot}2$ B.Th.U's.

The heat drop in the H.P. turbine is then

$$1{,}390{\cdot}1 - 1{,}189{\cdot}2 = 200{\cdot}9 \text{ B.Th.U's.}$$

Let the H.P. exhaust, at 72 lbs. per square inch absolute, be now reheated to 680 degrees F., the total heat will then be 1,375 B.Th.U's., and the entropy 1·8375 ranks. If there be a vacuum in the condenser of 29 inches (Hg.), with the barometer at 30 inches, H_s will then be 1,091·9 B.Th.U's., ϕ_s will be 2·0317 ranks, and the absolute temperature will be 538·5 degrees F.

The heat drop, from Callendar's formula, will then be $1{,}375{\cdot}0 - 1{,}091{\cdot}9 + 538{\cdot}5\ (2{\cdot}031 - 1{\cdot}8375)$, equal to 387·7 B.Th.U's. To this must be added the heat drop in the H.P. turbine amounting to 200·9 B.Th.U's., thus making a total heat drop of 588·6 B.Th.U's.

The theoretical steam consumption on the Rankine cycle is then

$$\frac{1{,}980{,}000 \text{ B.Th.U's. } (= 1 \text{ h.p.-hour})}{J = 777{\cdot}8 \times 588{\cdot}6 \text{ (heat drop)}} = 4{\cdot}324 \text{ pounds.}$$

If a turbine to propeller-shaft efficiency of 70 per cent. be

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assumed, the expected steam consumption per s.h.p. per hour works out at, say, 6·2 pounds.

The heat in saturated steam of 500 lbs. absolute pressure is 1,222·2 B.Th.U's., from which may be deducted 200 units as the heat in the feed-water, leaving 1,022·2 units, to which must be added 167·9 units for superheating to 750 degrees F. and 185·5 units for reheating the H.P. exhaust to 680 degrees F., making a total of, say, 1,376 B.Th.U's. per pound. Assuming a boiler efficiency of 84 per cent., the oil consumption per s.h.p. per hour will be

$$\frac{1{,}376 \text{ B.Th.U's.} \times 6{\cdot}2 \text{ lbs. per s.h.p.}}{18{,}500 \text{ B.Th.U's. per lb. of oil} \times {\cdot}84} = 0{\cdot}549 \text{ of a pound.}$$

Finally, taking the cost of oil given by Sir James, namely, £3 5s. 0d. = 780 pence per ton, the cost of one s.h.p. per hour is

$$\frac{{\cdot}549 \text{ lb. of oil} \times 780 \text{ pence per ton}}{2{,}240 \text{ lbs.}} = 0{\cdot}1912 \text{ of a penny,}$$

which gives 191·2 pence for 1,000 s.h.p. per hour.

Note. The turbine and boiler efficiencies taken above are those given by Mr. Stanley Cook in a paper read by him to Section G at the Southampton Meeting of the British Association.

At the same meeting Sir Archibald Denny said, in his presidential address to Section G: "Fuel-oil firing of boilers has been very largely adopted in steamships, with a marked gain in speed, and, when oil is marketed at certain figures, with economy of cost as compared with coal, not only on account of its relatively smaller weight consumption, but on account of the reduced crew required and the more regular speed obtained, hence shorter time at sea. But in considering the relative advantages of steam- and motor-driven ships, one must remember that an oil-fired steamship, in the event of oil soaring in price, may be converted to

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Mr. Thomas B. Mackenzie.
coal-burning, whilst in a motor ship the owner has not that option."

That, in my opinion, is a most important point, and one which should always be kept in mind.

Sir JAMES KEMNAL: Mr. Crush attributes to me the idea that the future boiler should not have any square headers or anything of that kind. That is not my opinion. Mr. Marriner, who supported Mr. Crush, puts the matter a little differently. He said that "the square or rectangular form of header has a tendency to get out of shape when exposed to very high pressures." I should like to say most emphatically that I believe that square headers will be essential to the water-tube boilers of the future. However, in that respect doctors differ. These gentlemen are entitled to their opinions, and I am entitled to mine. I can only say that boilers with square headers aggregating something like 20 million horse-power have given no trouble in the headers, nor have any of them burst or proved unsuitable for the designed purpose. Then a question was raised about solid-drawn drums, forged drums. They are really the same thing. I did not use the expression "forged drums," although they are forged. One speaker raised the question of whether the ends were solid in the steel-forged drums used in Babcock & Wilcox boilers. They were solid ends. The drum was made in a long run course, and the ends were swaged down and closed. In America, the steam drums made for 1,200 lbs. pressure were 4 inches thick, while in Amsterdam, steam drums for 650 lbs. pressure were $2\frac{1}{4}$ inches thick.

Mr. Weir mentions a great deal about the contamination of feed-water. Now that is not a question of pressure. Feed-water for boilers, properly speaking, should not be contaminated at any pressure, and I do not know whether the condenser has very much to do with it, because whatever the boiler pressure is it is obvious that the condenser keeps the

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same pressure. I am very glad to learn, however, that Mr. Weir has succeeded in putting the monel metal tube on the market commercially. I have no doubt that the porosity of condenser tubes will cease when monel tubes are used. But I should like to point out that something else is required to prevent leakage in the condenser; that is, glands must be abandoned, which can easily be done. About ten years ago I designed a condenser which had no soft packing at all, and the tubes to take up the expansion were slightly bent. I think that is a very fruitful source of research.

Mr. Hume refers to the reject temperature of boilers. Of course, that is not materially greater when working at a high pressure as compared with a low pressure, because, while the flue temperature has to be in excess of the steam temperature, there is not so much difference at high pressures as compared with lower pressures. I agree, however, that the air heater should be, in certain circumstances, better than economisers. Economisers for marine work are very unsuitable machines. No doubt there are many installations provided with air heaters. They do not happen to be Mr. Hume's air heaters, but still they are good air heaters in their way. With regard to Mr. Hume's boiler, it is very interesting to note that he has a shell boiler that will stand 400 or 500 lbs. pressure with five flues through it, and that his firm consider it a suitable boiler. I do not.

Mr. MacNicoll raises a point with regard to pressures of 250 and 500 lbs. If suitably made, I should deal with the two boilers in raising steam in exactly the same way. Naturally, there is no appreciable difference in the heating surface to evaporate a certain quantity of water.

Mr. Marriner mentions the Atmos boiler, which I have not seen, but it was visited by one of our chief engineers, who reported that it was too much of a toy to be of great practical use. The boiler can work at 1,400 lbs. pressure; at any rate, the boiler at Stockholm is expected to work at that pressure,

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Sir James Kemnal, F.R.S.E.

but from illustrations which I have seen the main work appears to be done in the superheater and in the economiser and not in the boiler, so that the smallness of the heating surface for evaporation is not at all remarkable. It has nothing to do but pass the hot water into steam. With regard to mechanical stokers, several ships fitted with Babcock & Wilcox boilers and mechanical stokers have operated in the Dutch East Indies for a very long time. The coal there is very smoky, and the mechanical stoker suits very well indeed. These ships are under a very competent superintendent, and he sees that his employees keep them in order.

Mr. Butler raises the question of manhole door joints, and as to how they are made. They are generally made of asbestos in some form or corrugated nickel rings, and they are held tight by the steam pressure, with the result that there is no leakage to bother anyone. If they were external joints, subject to steam pressure, there would be trouble; but as they are internal, the steam pressure tends to tighten them, always assuming that the machining is properly done. Another question asked was: What effect has the high temperature on superheater joints? Well, I regard 750 to 800 degrees F. as the limit of superheating, and under this temperature there is no appreciable detrimental softening of the material. That is perhaps the best way I can put it. Naturally there is softening, but the strength of the material is so far in excess of any stress it has to endure that there is no detrimental effect noticeable.

Mr. Brown refers to an illustration he has seen of an American boiler. I rather think it was a German boiler, made by Dr. Loeffler, to which I have given a great deal of earnest attention. It is an arrangement by which the water is circulated in a drum or boiler, in which heat is added by superheater coils in a brick furnace. I am unable to see that it possesses any advantages, and doubt if it is practicable for large installations. At present, however, there is an installa-

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tion being carried out in Austria which has got beyond the experimental stage, and it is associated with a turbine having various stages. If there were no disadvantages, it would be very nice to submit a number of coils to the fire and use the superheated steam in the coils to heat the boiler. But I do not think it will be found to be a practicable proposition. So far as I recollect, I think I have answered all the essential points, and I thank those present for the attention they have given to my paper.

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CAUSES OF DISTORTION IN THE ELECTRICAL REPRODUCTION OF SOUND

By Capt. P. P. Eckersley.

23rd February, 1926.

Introduction.

The fact that it is possible to communicate by speech over great distances by the aid of the so-called "telephone" is so well known that the *modus operandi* is apt to be forgotten.

The basic principles underlying wire telephony serve as an introduction to the subject to be discussed; replace the instrument of daily use by a "high quality" microphone, and substitute the wires which link but two points together by a symmetrical wireless wave radiator, and broadcasting is the result. The chief causes of distortion lie in each end of the chain, and the major part of this paper will be devoted to microphone and receiver.

My excuse, then, for introducing into this paper an explanation of the ordinary wire telephone will be unnecessary, since the principle is basic to all that follows.

The Principle of Wired Telephony.

Sound Waves. Sound is a wave motion in air. When periodic impulses of higher or lower pressure are created in the air by any means, we have a note. A tuning fork in vibrating gives little "pats" and "sucks" to the surrounding air, and in moving outwards creates a higher pressure in front of it; in returning inwards it sucks a vacuum where a moment before higher pressure existed. A lady's fan moved to and

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fro will illustrate at a lower frequency what happens with the rapidly humming fork. The little "puffs" and "vacuua" created in front of the fork are pushed outwards and away from the fork by identical following puffs and rarefactions, and so a train of waves moves outwards. The human ear is capable of distinguishing the frequency of the puffs and rarefactions, *i.e.*, the number impinging upon the ear per second, in a remarkable degree. When the puffs come very fast we hear a high note. (The top of the piano scale gives 2,000 puffs or rarefactions a second.) When they are slow we hear a bass note. A "noise" is a jumble of many discordant frequencies unrelated to one another in any definite way. Certain ears are capable of hearing as many as 30,000 vibrations a second, according to some observers, and as low as 16 vibrations; a considerable gamut. In music the usual scale is actually from about 30 to 3,000, but the timbre of instruments is distinguishable by the wealth of their harmonics. Thus, although a violin may produce a fundamental note of 1,000, that note is given its peculiar characteristic sound by possessing also components of even multiples of 1,000, such as two, three, four, five, up to ten thousand. Wind instruments have usually fewer harmonics than stringed.

The Microphone. Sound waves attenuate rapidly. A brass band can be heard for several miles under favourable conditions; the sound of the guns fired off Spithead during naval reviews has been heard as far away as Lincolnshire; many remember standing on the Kent hills during the war and hearing the sound of the guns on the French front. This shows that even to carry over distances small compared with those associated with the wire or wireless telephone, great intensity is required at the source to enable sound waves to carry. In Britain we have heard an American talking in New York; voice communication with the Antipodes has been achieved; speaking from Glasgow to London is an everyday occurrence. Thus it is that the microphone has helped to

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overcome the impossibility of using sound itself for long-distance communication.

The microphone consists essentially of an apparatus which, with associated circuits, raises and lowers electrical pressure in sympathy with the static or dynamic changes of air pressure around it. In one of its earliest and probably its most persistent form, it consists of a diaphragm free to move, one side of which is open to the air, while the other presses on carbon granules, pressing more strongly as it is forced inwards by the increasing external pressure of air, more lightly in the converse condition. The changing pressure of air on the diaphragm causes corresponding changes of pressure on the carbon granules, and this causes a change of electric current through the granules. The electric current thus changes its rate of flow sympathetically with the changing pressure on the diaphragm; as is stated in popular explanations "sound is converted into electricity."

The Telephone. By connecting the wire that forms a circuit with the necessary battery and the microphone also through a telephone, a communication is achieved. The telephone is the instrument which converts back into sound the electrical variations of current. It, too, commonly consists of a diaphragm, which, made of magnetic material, is sucked in towards the magnet, which it faces, as the current increases, and moves away as the operating current decreases, and in moving creates, as did the tuning fork, compressions and rarefactions in front of it, exactly copying, assuming no distortions, the movements of the microphone diaphragm.

To recapitulate (refer to Fig. 1). Supposing there is a desire to reproduce the sound of a tuning fork vibrating in London in a room in Glasgow. The apparatus used is a microphone in London and a telephone in Glasgow, a battery and a length of wire continuous between the places. The tuning fork is set vibrating, and creates a train of little puffs of higher pressure and sucks of lower pressure radiating

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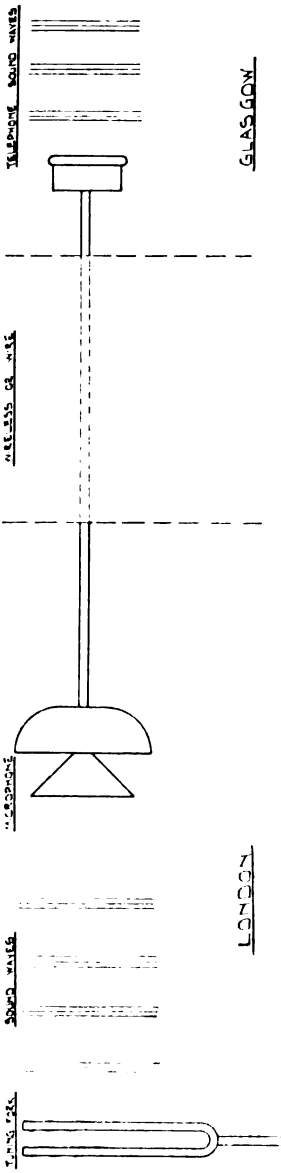

FIG. 1.

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from it. These impinge upon a microphone in the near vicinity, and the little taps and sucks given to the microphone diaphragm cause it, thanks to its contained carbon granules, to change its electrical resistance.

The battery thus sends round the circuit containing the microphone and telephone, currents which vary as the resistance of the microphone varies. These varying currents pass through the operating coils of the telephone, and, due to the consequent change in pull of the magnets on the telephone diaphragm, cause it to wobble and produce puffs and sucks, *i.e.*, sound waves, in the room at Glasgow. These are eventually heard by anyone wearing the 'phones.

No apology is made for explaining the basic principles as stated above, nor for the fact that many practical details (transformers for connection to long lines, etc.) are left out. The simplicity of the idea is fundamental to an understanding of the problems of doing exactly the thing described without distortion.

Causes of Distortion.

Basic to the Microphone. It has already been explained that the ear is capable of appreciating air vibrations over the gamut of frequencies lying between 16 and 30,000. For present purposes, however, perfection can justly be assumed if vibrations between 50 and 10,000 can be dealt with faithfully.

The Diaphragm. It will be at once apparent that the diaphragm of the microphone must be capable of responding to all these frequencies without minimising some in favour of others, or else immediately distortion will arise.

Take, for instance, the case just discussed of a small rigidly held diaphragm; it is obvious that it will have certain intrinsic resonances mechanically. In the ordinary microphone such as is in daily use in our houses and offices, the diaphragm certainly possesses these resonances, and will respond to air vibration frequencies of from 1,000 to 2,000 far more readily

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than those of 50 or 5,000; in fact, it is doubtful whether it responds to these latter frequencies at all. It is, however, a fact that the ear is able readily to make severely distorted speech intelligible if but a few of the originally produced frequencies are present. Thus, although perfectly natural speech may contain certain frequencies over a gamut of from 200 to 8,000, it is possible to distinguish what is being said even though a quarter only of that gamut is used. This is a fortunate fact for the telephone engineer. From the broadcast problem, however, it stands in the way of the ideal of producing perfect naturalness. For the perfect reproduction of music it is the more important to have a representation of the whole gamut, since music depends so much for its character, if not for its melody, upon the proper representation of the warm bass notes and the higher harmonics.

Thus the first cause of distortion may be looked for in the microphone itself, and obviously a mechanically resonant diaphragm is an immediate bar to perfection.

Standing Waves.

When listening to a sound, we have two ears with which to apprehend the air disturbance. Thus the state of the air as between one ear and the microphone, which might be called the instant field strength in the air, is not so important, inasmuch as the peculiarities of the state *vis à vis* one ear may be corrected in the other. Shut one ear when listening to an orchestra, and notice the curious result. Notice when the tuning note is given from the broadcasting station (a high-pitched continuous note) how, if one ear is blocked up and the head moved, the intensity of the note may vary almost a hundredfold. The observed effects with single ear hearing are probably due to "standing" waves. A wave impinges upon the ear and surrounds the head, and the higher frequency waves are reflected back towards the source. At particular distances and frequencies the reflected wave may

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interfere with the oncoming wave, and a null state of variation of air pressure may blanket the ear. Reflected waves can be noticed interfering with direct when a deep sea beats against a flat concrete face, and can be observed against the promenades of certain seaside resorts. On a smaller scale, a swimming bath shows the same effect.

The microphone, if it presents a large normal surface to the direction of propagation of the waves, may create standing waves which minimise certain notes in favour of others, owing to distortion in the sound field.

Minimisation of Lower Frequencies—The Baffle.

The long waves of sound, *i.e.*, the lower frequencies, may exert a less force upon the diaphragm of the microphone than the higher, owing to the bending of the wave around the obstacle and the escape of pressure around the sides of the microphone.

Perhaps it is easier to illustrate this principle by asking readers to consult their experience with water waves. Suppose a rock stands in the sea, and the waves are surging round it. If the rock is small compared with the wave-length (which at sea may be 50 feet, perhaps), the general wave form is little changed by the rock; the waves slip round behind, and reform almost as if the rock did not exist. Short wave ripples on a calm day slap the surface of the rock, and a calm exists on the lee side. The same with air waves and the microphone. The long waves of lower frequency may not notice the presence of the microphone, and the field is little distorted; the waves reform behind the rock almost as if it were non-existent. The short waves, the ripples of the analogy, slap the relatively large diaphragm, doing more work. Thus, assuming equal intensity of pressure over all wave-lengths (all frequencies), the lower tones may be minimised. A simple experiment shows very clearly the described effect. By surrounding a microphone by a large baffle, leaving a large

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flat surface normal to the waves (increasing the size of the rock), the long waves are not allowed to bend, but are made to slap the diaphragm and do more work. Naturally, the effect of standing waves is increased.

Response Characteristics.

It will be apparent that a device is required which responds to all frequencies over the considered gamut. Consider, then, a diaphragm free to move in space, of a size large compared with the largest wave-length of sound, and as a mass m without characteristic mechanical resonances. Neglecting the effect of standing waves,

$F = m \cdot \frac{d^2v}{dt^2}$, where F is the force exerted by the air wave, and v the velocity of movement under the influence of the force F, and

$F = A \sin pt$, where A is a constant and $p = 2\pi \times$ the frequency.

Then $A \sin pt = m \cdot \frac{d^2v}{dt^2}$, and

$\frac{dv}{dt} = \frac{A}{mp} \cdot \cos pt$ (see Fig. 2).

Assume that the rate of change of velocity is proportional to the change of electrical pressure in the microphone. Then if these assumptions are justified, it will be seen, assuming no characteristic resonances, that the application of a sinusoidal air-pressure wave results in an electric response, which increases with decreasing frequency. Again, assume that the change of current in the microphone is equal to the displacement of the diaphragm (s which equals vt), then the response to equal forces in the air is $\frac{1}{p^2}$. This might seem to introduce a potential distortion, since a response independent of p has been required.

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It is, however, obvious that this is not necessarily so. Suppose the telephone at the other end gives a response propor-

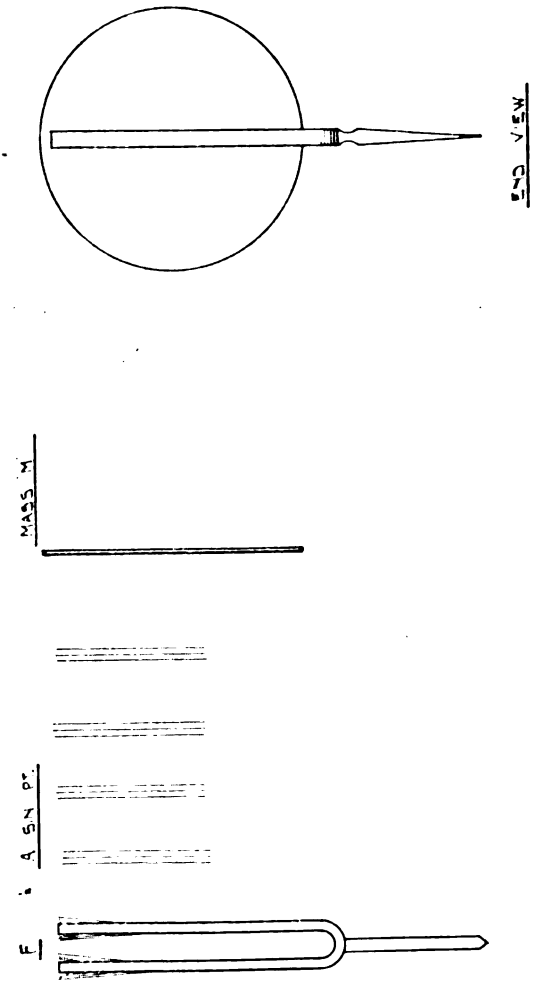

Fig. 2.

tional to p, then in the first case (*i.e.*, microphone response equal to $\frac{1}{p}$), the overall system would be apparently perfect,

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since the two response characteristics will cancel out. Furthermore, even if an inverse response in the telephones could not be obtained, it is perfectly possible to obtain "correction" in the circuits. For instance, in a microphone and telephone system which responds theoretically to an inverse frequency characteristic, the introduction of an impedance which is proportional to p in the circuits serves to cancel the inverse characteristic.

It is now pertinent to discuss, then, at this stage what constitutes an ideal response characteristic in a microphone. In the first place, it is obvious that a "smooth" characteristic response is required. If we had to contend with a diaphragm which had acute mechanical resonances which were not proportional to some obvious function of the frequency, they would be impractical to correct. Thus a "smooth" response proportional to p, p^2, $\frac{1}{p^2}$, $\frac{1}{p}$, for equal force or some such simple function, is required.

So far response has been considered for equal force which is equal pressure, in the air wave. Suppose, then, that a smooth response curve has been achieved, and by suitable correction in the circuits associated with the microphone, equal electrical response for equal pressure in the air wave at the microphone has been obtained. Is this ideal? The pressure at low frequencies is greatly in excess of that at high frequencies. There is a limit of power in the system, and obviously, if power is wasted for the production of low notes in favour of high, full efficiency is not being achieved, although theoretically if the microphone gives equal electrical response for equal pressure of air wave, and the loud speaker or telephone gives equal pressure of air wave for equal electrical input, then there is a perfect system, except, as stated above, that such a system may be wasteful.

There are some, therefore, who argue that to achieve a higher efficiency the microphone should give equal electrical

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response for equal audibility. Thus they say an orchestra has been designed so that in general every instrument in it shall give an equal "sensation" to the human ear listening in the room. True it is that a distance test, *i.e.*, going further and further from an orchestra to find out which instrument is heard last, may seem to show that an orchestra has not been designed for equal audibility; but attenuation here plays a part, and listening at a reasonable distance must be considered.

If the microphone gives an equal response to every instrument in the orchestra, then the violins have an equal chance with the piccolo, the brass with the 'cello, and so on, and the power of the system is in no case limited to one particular instrument. The equal pressure exponents ask how it is possible to base reasoning upon immeasurable hypotheses, and why should the physiological idiosyncrasies of the ear be considered?

My opinion is that in no case has any perfect response to any *exact* physical basis been achieved; owing to the extreme difficulties of measurement in acoustics, a somewhat "hit and miss" basis has been chosen. True it is that Americans have attempted measurement, but, while the ingenuity and analytical faculties of those entrusted with the research are to be admired, perfect conviction is not yet established, at any rate in my mind.

Actual Microphones Proposed and Used.

Neglecting the ordinary telephone microphone, ideal for its purpose where intelligibility and sensitivity, but not perfection, are required, it may be interesting to describe existing types of "perfect quality" microphone. It should be remembered that in every case freedom from mechanical resonance has been sought by the inventors. Illustrations of the Marconi-Sykes and Western Electric microphones are given in Figs. 3 and 4, respectively.

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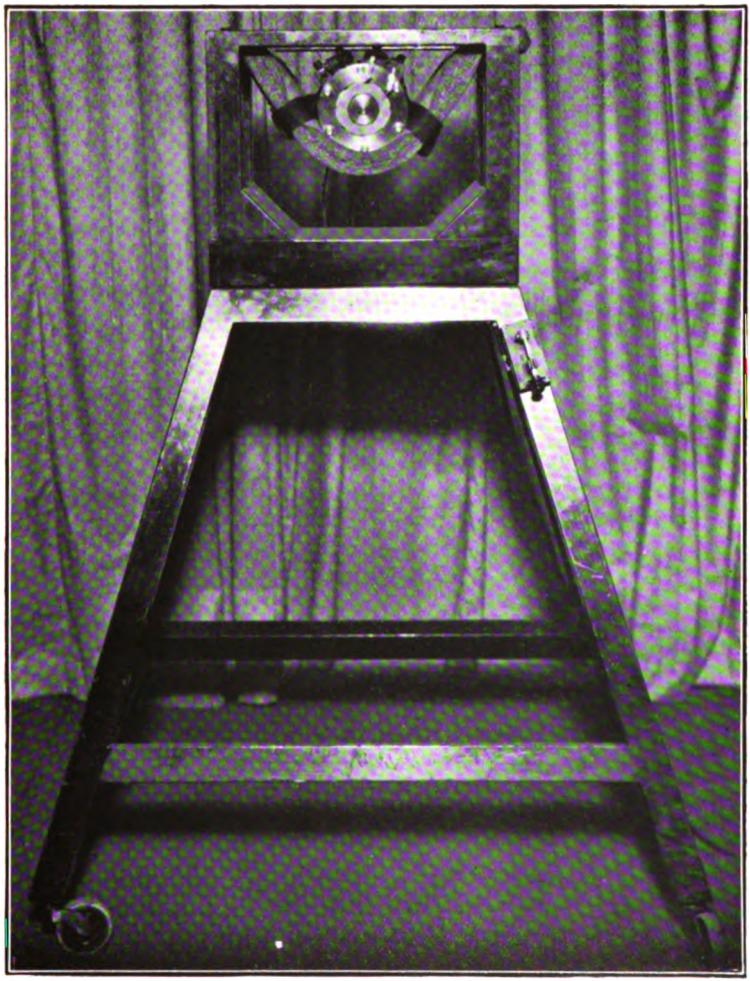

Fig. 3.—Marconi-Sykes Microphone.

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Fig. 4.—Western Electric Microphone.

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The Western Electric Carbon Microphone.

In this type the diaphragm is stretched so tight as to have a mechanical resonance well above 10,000 vibrations a second. This at once achieves theoretical mechanical aperiodicity in the band of frequencies considered. Apart from this ingenious method of ordinary mechanical resonances, the microphone is of the carbon type. In all cases where aperiodicity is achieved, the sensitivity of the device is decreased; the ordinary post office microphone is sensitive, simply because of its intended mechanical resonances within the band of intelligible frequencies. Cut out resonance, and sensitivity decreases. In the carbon microphone described, it is necessary to add a valve amplifier to bring up the sensitivity to that necessary for transmission over a line or by wireless. Consequently, the "hiss" of the current passing the casual contacts between carbon and diaphragm is amplified, and so the use of the device for picking up weak sounds is limited owing to the presence of hiss. As long as the impinging sound is great enough to render high amplification unnecessary, the device is useful. It has been largely used by The British Broadcasting Co. for "outside" transmissions, *i.e.*, those taking place in cafés, restaurants, theatres, dance halls, etc.

The Western Electric Capacity Microphone.

Another type of microphone, largely used in America, is the capacity type. Here a stretched diaphragm, as used in the carbon type, forms one plate of a condenser. A thin dielectric separates this from a fixed plate. The two plates are charged through a resistance by a fairly high-voltage battery. The impinging sounds change the capacity of the device, and sympathetic currents flow through the resistance to change the varying capacity. The changes of voltage across the resistance can be amplified. The device is insensitive compared with the carbon type, but larger amplification is

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possible since carbon hiss has no longer to be contended with. The extremely high resistance necessary renders long connecting cables from microphone to amplifier impossible, and insulation difficulties are sometimes considerable. In many cases, to keep "leads" short the first valve of the amplifier is contained in the same housing as the microphone itself.

The Marconi-Sykes Microphone.

The Marconi-Sykes, very often called the Round-Sykes, since Capt. Round did so much development work upon it after Mr. Sykes had patented the principle, is of the electromagnetic type. Here an annular ring of paper supports a spiral of fine aluminium silk-covered wires in a strong magnetic field. The ring is held by vaseline-covered cotton wool, and is practically aperiodic, due to its "squdgy" mechanical nature. The sound waves impinging upon the ring cause its movement as a mass, free in space theoretically, and since the wire cuts normal magnetic lines, feeble currents are created in it, which are later amplified. The device has been used as standard for all studios of The British Broadcasting Co. There is a tendency for slightly mechanical resonance at low tones, and it is not easy to correct for all the idiosynerasies of the device. The mathematical analysis of the response is that given on page 547, but obviously the form of the ring allows more work to be done on it at high frequencies. Correction circuits are introduced in the amplifiers to overcome certain tendencies such as too low resonant and too high "S" tones.

The Reiss Microphone.

One of the latest microphones to be introduced, is called after its German inventor, Reiss. This consists essentially of a layer of carbon. Carbon, finely dusted over a surface of marble, is kept at a constant or nearly constant depth by a rigid or semi-rigid covering. The sound hitting this covering

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causes sympathetic charges of resistance in the carbon. This is largely overcome by introducing the current *via* a pocket at right angles to the layer in which the carbon is packed tightly on to the electrode. Hiss in carbon microphones is largely caused by the loose contact between the carbon and metal; in this case it is obviated in the ingenious manner described.

The device is simple, sensitive, and small, and bids fair to rival in performance many existing types. The British Broadcasting Co. are experimenting with different types of this device, but as tests are still in progress much of the interesting data obtained by Capt. Round cannot be here given.

It should be noted that in all microphones it is essential to have a suspension of rubber or equivalent non-resonant substance. The rigid holding of microphones in solid supports introduces mechanical resonances.

Loud Speaker and Telephones.

Leaving out of account, at the moment, the question of distortionless amplification, we arrive at the telephone and loud speaker problem, the turning back of electrical impulse into direct sound.

Basically, the loud speaker must, assuming a perfectly responding microphone, give an inverse effect. If the supplying of an equal pressure of air wave at the microphone produces an equal electrical impulse, then equal electrical impulse input to the loud speaker must produce equal pressure of air wave. At the lower frequencies, it will be readily understood from the discussion of the long wave bending that, unless some form of baffle is used, the movements of the diaphragm must be very considerable to do the necessary work on the air to produce equal pressure.

I do not intend to discuss the theory of the telephone, since it is not sufficiently established to merit discussion. This at least can be said, that, thanks to the damping of the ear cavity,

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telephones compare extremely favourable with the common types of loud speaker.

In its usual form the loud speaker consists of a magnetic diaphragm, which is attracted, to a varying degree, by fixed magnets in the operating coils, from which flow the alternating currents created originally by the microphone. A cavity above the diaphragm tapers to a neck, to which is attached a horn, which bells outwards towards its mouth. The chief difficulty experienced in designing a loud speaker is to prevent the diaphragm from responding more to the middle than to the ends of the frequency gamut.

The snarling nasal tones are due to the superior chance given to small diaphragms to do work on the air at from 1,000 to 2,000 frequencies, their mechanical inertia, on the other hand, frequently preventing them vibrating as a whole to the extremely high frequency.

To create the lower frequencies in their just proportion, large diaphragm movements are essential. The horn, by partial air resonance of its contained air column, tends to amplify the lower notes, and the bass tones can be almost indefinitely magnified in terms of the horn. The type of horn usually favoured by designers is called the logarithmic type, in which the diameter of the horn increases in a logarithmic curve as the distance from the diaphragm increases. For the sake of compactness the horn is often "swan necked," Fig. 5, but this affects its working to no great extent. It will be appreciated that the horn helps the lower notes by air column resonance, and to this extent it is by no means the perfect solution, purely because it is nearly always too short, and if long enough gives the "hang on" effect. A piano's low note struck and damped out may continue, after the damping is applied, for one-tenth of a second (a purely fictitious figure for the sake of illustrating a principle). Resonance in the horn may increase this period to five-tenths of a second, and the "clear cut" character of piano playing may be lost.

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Whatever may be done to increase the bass notes in the ordinary type of loud speakers by the introduction of horns and other methods, it is certain that the limitation of displacement of the small diaphragms will be the paramount difficulty

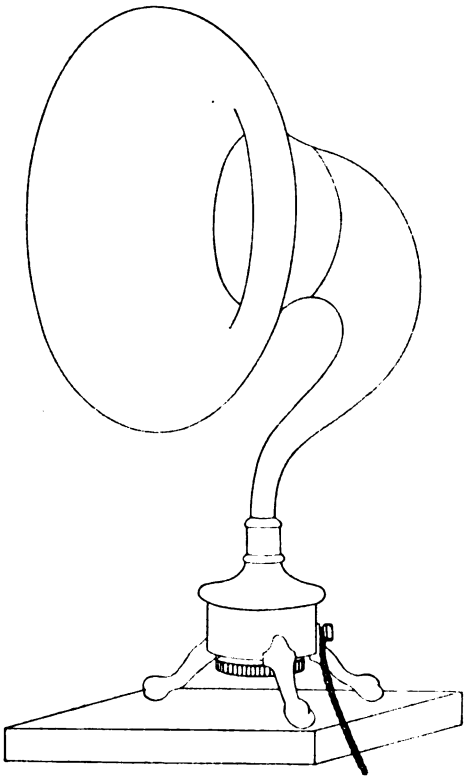

Fig. 5.

in producing perfect quality. A great deal can be done to make loud speakers more perfect by an alteration in mechanical rigidity of construction. In two almost identical speakers, one is far superior to the other simply on this account. Realising these limitations, some inventors have taken steps to introduce a better response. Certain designs embody two loud

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speakers, one with all the devices applied to introduce the low tones, the other taking care of the high tones.

The hornless loud speaker is already gaining adherents. In general, it consists of a cone-shaped or flat disc, the centre of which is made to move by a magnet system. The drum-like form of the device is frequently used to create bass resonance.

The "boom" tone due to reliance upon resonance is a typical quality of such speakers, although certain types show a tremendous advance over the older horn type. So long, however, as the movements at bass notes are limited by mechanical considerations, but given spurious predominance in terms of resonance, so long will listeners continue to experience the boom tone which prevents the clear cut character of speech, and of piano music if not of organ and the slower type of orchestral music.

In the case where a magnetic relay operates any movement, it must be obvious that the pull is dependent upon the distance of the moving armature from the magnet. Thus if higher frequencies are superimposed upon lower, the magnetic pull at such frequencies is different during different times, and potential distortion is introduced.

A loud speaker recently patented by the Americans, Rice and Kellog, seems theoretically to possess certain features which render it immune from the difficulties endemic to the more conventional types. It consists of a cone of paper, held at its edges very loosely by rubber, and free, therefore, to move laterally (through half-an-inch at least), and has no essential characteristic resonance except perhaps at about two or three vibrations a second. Attached to the cone is a coil working in a magnetic field, Fig. 6. Alternating currents in this coil cause lateral movements of the cone, forcing the air out in front. The pull at all amplitudes is practically constant; except for the slight restraint of the rubber at the edges, the movement can, without distortion, be up to the order of an

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inch; no spurious resonance will be required to bring out the bass, and the movement can be extremely light and inertialess.

The chiefly remarkable point about the device is the use of the baffle. Already the difficulty of doing work upon the air at low frequencies has been explained, and the aid of the baffle with the microphone has been discussed. In a like manner, obviously, the baffle helps the loud-speaker movement

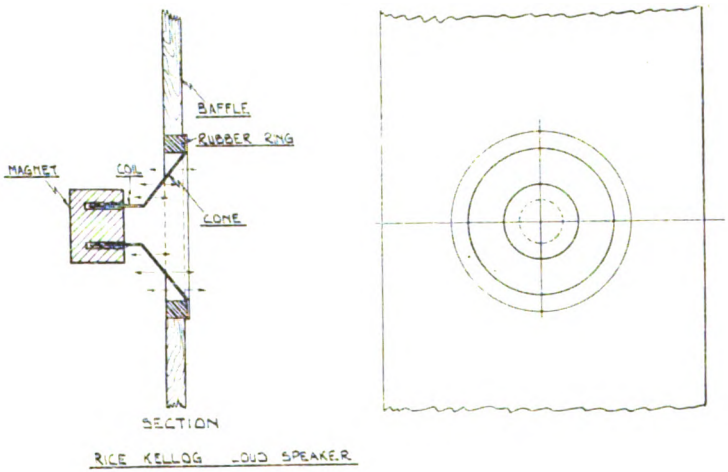

Fig. 6.

to prevent the escape of the longer waves behind the moving diaphragm. The effect is truly remarkable.

Doubtless there will always be the difficulty of centering the coil in the gap, which increases the flux density the smaller it is allowed to become. More, it might be expected that the characteristic resonances of the cone itself, the harsh scraping sound of the paper it may be, might give an "essy" sound to the reproduction; but these are chiefly theoretical objections.

The lines along which loud speakers must develop is to

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allow reproduction over the full gamut in terms of aperiodicity of movement, and large allowable movement for the bass tones, not depending upon the adventitious aids of the horn's mechanical resonances, and so forth.

It would be greatly helpful if the question of efficiency were studied more. At present a distortionless amplifier producing sounds from a loud speaker of equal intensity with the original, if this were a piano, might be of the order of 400 volts at 50 milliamps. or 20 watts. The piano probably produces one-half watt on the same basis. It is a fact that reproduction cannot be perfect, owing to the peculiarities of our ears, until the reproduction is no louder nor softer than the original. Control of the intensity of the received signals is important when perfection is sought; an overloud voice, an oversoft piano, means distortion.

Distortion in Amplifiers.

There is necessarily a chain of amplifiers in a system using high-quality microphones and loud speakers. Where wire joins microphone to loud speaker direct, there is the microphone amplifier; only where wireless is interposed are there both microphone and loud-speaker amplifiers. The problem is simple in essence. It is to achieve amplifiers which give equal magnification to equal impulses of from 50 to 10,000 cycles a second. A properly designed resistance capacity amplifier need introduce no distortion; it is in the transformer where the chief causes of distortion lie.

The study of transformers involves a paper in itself. The basic principle is to treat all transformers where work has to be done, as power transformers, giving them perfect regulation and over-designing them against the highest load. Suffice it to say that the application of these principles has resulted in a practically perfect transformer in the experimental laboratories of The British Broadcasting Co.

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Wireless Distortion.

Transmitters. Here again the application of the "power" idea prevents much distortion. The systems used in the past will probably give way to methods using as little iron as possible in the circuits. There is not space here to discuss what is, in essence, a simple electrical problem, however difficult it may be to achieve a practical solution.

Receivers. There need be no distortion whatsoever in receivers. Plain straight-forward high-frequency amplification results in no distortion. Detection is a fruitful source of distortion, and naturally if bad transformers or incorrect valves and low frequency arrangements are used, other troubles will arise. It is, at any rate, interesting to know that quantitative measurements show that the perfect receiver (*not* including the loud speaker) is not only theoretically possible but practically so.

The detector can conveniently be crystal, but this is not to say that the valve cannot be used. The grid-leak method of rectification in the valve is frequently abused in a search for strength of signal rather than quality of signal. A too high value of leak, a too large value of leak condenser, frequently spells disaster. The type of valve with fine mesh and a high impedance value, if properly treated, gives practically perfect rectification, although there are other methods, which I cannot at present reveal, which come nearer still to the ideal.

The chief failure with low frequency is the use of poor transformers, and the fear of a sufficient value of high-tension voltage. I look forward to the time when the ordinary house electric-mains will supply all the power for wireless receiving sets, and when pressures of 500 volts and real power valves will be common in the average set. Not until then will there be freedom from the slight distortions incident to reception on valves without a real factor of safety in characteristic curvature or grid current distortion.

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Conclusion.

Apology is needed for the scope of this paper being too wide, but it is thought that as general literature is not available a general survey might be acceptable. That the wireless link between microphone and loud speaker has been discussed so cursorily is explained in the above terms, since its introduction is but incidental to the main argument. The greatest problem, the basic problem in fact, lies around the conversions from sound to electrical impulse and back from electrical impulse to sound again.

The problem is as fascinating as it is complex, a knowledge of acoustics, mechanics, wave motions, and electricity being essential to its fullest appreciation. I realise to the full my unworthiness to pretend to fulfill these qualications, and feel that this paper would be incomplete without acknowledging the debt that I and British broadcasting owe to Capt. H. J. Round. His continued and successful application to the problems which surround the microphone and the loud speaker are appreciated by all interested workers in the same field.

Discussion.

Mr. C. R. H. Boxx (Associate Member): Capt. Eckersley has obviously written his paper with a view to making what is really a very involved subject more or less clear to those who, although intensely interested, are not equipped with sufficient technical knowledge to study the matter at first hand, and the verdict must be that he has been eminently successful.

But the ingenious simplicity of his explanations covers a lot of very important points—points which are too often insufficiently considered or neglected by those studying the question. I refer particularly to the minimisation of the lower frequencies owing to the escape of pressure round the object struck, and standing waves. I should like Capt. Eckersley to make

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the relationship between the energy of the wave and its propagation a little plainer. Undoubtedly waves of low frequency do tend to escape round the object struck, but this, as he shows, is easily corrected by the use of a baffle. Apart from the distortions inherent in the apparatus, the chief difficulty seems to me to be that sounds of low intensity lose most in propagation, and this loss will be the more noticeable the weaker the propagation. This explains why headphones are generally so superior to the loud speaker. In the case of the 'phones, the lugs act as speaking tubes, and thus conserve the energy of the less intense sounds, whereas with the loud speaker the energy, and hence the intensity, of sounds are considerably diminished before they reach the ears of the audience. It appears to be wrong in principle to try to propagate sounds by means of a flat diaphragm, as is done in the case of the ordinary loud speaker, because there must necessarily be much distortion of the lower notes. I am of opinion that this distortion could be largely overcome by carrying forward the train of waves on a column of air, as in the case of the human voice, and I should like to know what Capt. Eckersley thinks of this proposal. This method would, of course, raise the pitch according to Doppler's principle, but the rise would be too slight to be of any practical consideration.

I remember seeing, many years ago, a novel sound-box fitted to a gramophone called the "Stentorphone," invented, I believe, by Sir Charles Parsons. This consisted of a chamber A, Fig. 7, having slits 1 on one face. To this face was hinged a grid B, actuated by the usual gramophone needle C. The grid had slits 2 similar to slits 1, but so arranged that they covered the bars between slits 1. Normally, there was a slight clearance between the surface of chamber A and that of grid B. Air, at a low pressure, was admitted to A, and its varying rate of escape through the slits 1 governed by the movement of grid B, in response to the needle C as it moved in the groove of the gramophone record, reproduced the sounds recorded.

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Mr. C. R. H. Bonn.

This instrument produced remarkably powerful effects. I was told that resonating glass vessels had been shivered to atoms

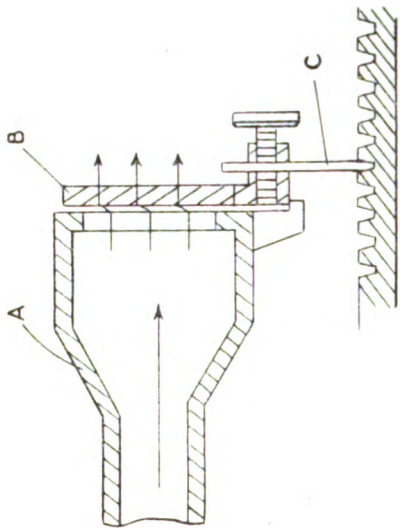
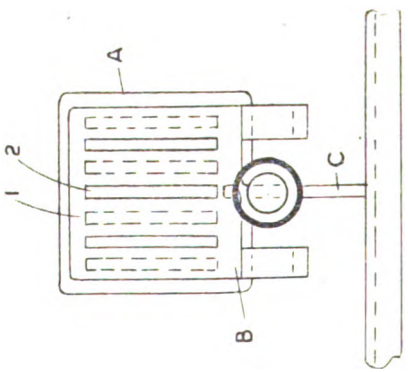


Fig. 7.



by notes produced by it. As far as I can remember, the quality was good, but I do not claim to have such a remarkable ear as Capt. Eckersley.

The air itself is aperiodic, and if vibrations could be received

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from the air and given back again without the use of vibrating bodies, which, however light and well damped, have a period, and if, moreover, both microphone and loud speaker could be so contrived as to have the same characteristics, so that distortion from these sources was cancelled out, the problem of distortionless transmission would be practically solved. The nearest approach to anything like the suggested microphone I have seen is one in which use is made of the sensitivity to pressure of a brush discharge across a narrow gap. No doubt Capt. Eckersley could give some information concerning this feature. It has occurred to me that the sensitive gap microphone and some form of stentorphone loud speaker might be the nearest possible approach to the solution of the problem.

I can understand that standing waves caused by adjacent surfaces can affect the microphone, but I quite fail to understand how standing waves created by the microphone itself, as stated on page 546, can affect its reception.

Capt. ECKERSLEY: Mr. Bonn states, in effect, that attenuation does much to limit the bass tones, and cites the different observed effects with the telephone, in contradistinction in distance relationship, to the loud speaker.

I am of the opinion that the telephone gains in quality, not due to the nearness of its movement to the apparatus of human reception, but rather to the enclosure of the air contained in the air cavity formed between earpiece and ear. 'Phones held from the head only a fraction of an inch become tinny and high pitched; a close-fitting 'phone pressed to form a seal against the ear gives an entirely different and "warm" type of music.

If the loud speaker were to produce its low tones in their correct proportion, we should have no complaint, but, as Mr. Bonn justly observes, attenuation exaggerates their diminution, and the head placed in the mouth of the speaker's horn often introduces a surprising gain in warmth of music. There

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Capt. P. P. Eckersley.
is, I think, an effect of "masking" by low tones, which means that if a bass note exceeds a certain value it appears relatively to diminish the higher note, hence the double or even treble effect of listening close up to the horn. Further, of course, with the head close to the horn, the escape of the long waves has not yet taken place, and the listener is in a more intense field of sound for that reason.

I recollect the Stentorphone. During the war there was a proposal to use such a device for communicating by a "stentorian" voice direct to aeroplanes flying in the near vicinity. Wireless telephony, however, seemed a more practical solution of the problem. I am not acquainted with the difficulties that were experienced in later developments, but the only time I heard the apparatus (from a van advertising a well-known newspaper) they had not been overcome. Among possible sources of trouble, I foresee moisture condensation on the moving "combs" and difficulty of avoiding mechanical chatter and resonance, but these are theoretical disadvantages; I know nothing of how they may have been overcome, or of others that may have arisen.

The brush discharge or flame microphones seem at first to present ideal qualities. Who ever heard of mechanical resonance in a brush discharge? Unfortunately, the brush discharge has to occur between electrodes. The electrodes must be supported mechanically, and too often it is forgotten that these, too, come within the field of air-pressure variation. This immediately introduces the problem of mechanical resonance which we seek to overcome, and, therefore, the device possesses no intrinsic merit over others which rely upon some form of support to an armature, whether solid, electric, liquid, or gaseous.

Finally, I cannot have made myself clear on the question of distortion by standing waves against the microphone itself. I meant to indicate that as any microphone presents a surface normal, or nearly normal, to the wave front, a reflected wave

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must tend to interfere with the direct wave. This, under certain conditions, may produce nodal or anti-nodal states of pressure variation at the movement of the microphone, and so depress or augment one frequency in favour of another. With two ears the cancellation at one is not noticed, thanks to the presence of the other in a different part of the "sound" field. This contention can be proved, as indicated in the paper, by stopping up one ear and moving the head about during the production of a note of, say, 1,000 vibrations or upwards. The microphone is a single ear, hence a possible and, with certain arrangements, measurable and actually measured source of distortion. Often, when a peculiar distortion occurs, the movement of the microphone by a few inches removes the trouble.

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THE DEVELOPMENT OF THE NOBEL ENGINE.

By P. H. Dixon Wilson.

9th March, 1926.

Appreciating the great possibilities of the Diesel engine after witnessing tests on the first commercially practical engine, Ludwig Nobel, Ltd., of Petrograd, completed licence arrangements for the construction of this new prime mover in 1897, and immediately proceeded to construct their first engine of this type.

The Nobel engine followed very closely in general outline the German design, and was of the single-cylinder crosshead four-stroke cycle type. The cylinders were 260 mm. (10¼ in.) in diameter, with a stroke of 410 mm. (16⅛ in.); and the engine, Fig. 1, developed 20 b.h.p. at 200 r.p.m.*

As the first British Diesel engine was manufactured in this city just previous to the one described above, namely, in 1897, by the Mirrlees Watson Co., Ltd., it might be interesting to give the cylinder dimensions. These were:—Diameter 10 in., and stroke 16 in.; and the engine, Fig. 2, developed 20 b.h.p. at 200 r.p.m. This engine is still, after 29 years, doing useful work daily at the works of Mirrlees, Bickerton & Day, Ltd., Stockport, which company was formed in 1908 to build a special works and devote their energies to the development of the "Mirrlees-Diesel" engine. They are now manufacturing the two-stroke cycle Nobel engine, to be described later,

* All figures in the text given for engines manufactured by the Nobel Co. refer to the metric system, i.e., b.h.p. is really metric brake horse-power, which is 1·39 per cent. less than British b.h.p.

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as well as the many types of the four-stroke cycle engine they have developed.

Reverting to the Nobel engine, a 30 b.h.p. per cylinder crosshead type, built in sizes having one or two cylinders, was put on the market in 1900. The first customers for the Nobel engine were the Nobel Brothers Petroleum Production Co. and the Russian War Office. Several engines were put into the Nobel Oil Refinery at Baku in 1900, and following this a new type of Diesel engine, 100 b.h.p., in two cylinders, was designed. In this the trunk piston was used, and three such sets were installed at the Baku Pumping Station in 1902, to be followed by others until all the pumping stations on the line were fitted out with Diesel engines.

The two-stroke cycle had always appealed to the Nobel engineers, and by this time a 13½ b.h.p. horizontal single-cylinder two-stroke hot-bulb engine had been produced; but as there were further developments with the four-stroke cycle type, these will be described now, and detailed reference made to the two-stroke cycle engines later.

The largest type of four-stroke stationary engines built by Nobels was that of 200 b.h.p. per cylinder at 150 r.p.m., and the cylinder dimensions were:—Diameter 600 mm. (23⅝ in.), and stroke 800 mm. (31½ in.). Two three-cylinder engines, *i.e.*, 600 b.h.p. per engine of this type, were installed in the Moscow Metal Works, Ltd., in 1907, one of these engines being direct coupled to the rolling mills. This work involved a constantly varying load, from practically no load to overload and *vice versa*, and the fact that this engine has done this work for 19 years proves the reliability of the Diesel engine. Another interesting installation was that of an 800 b.h.p. engine at the Tzaritzin Flour Mills.

As it was in designing and building of marine Diesel engines that Nobels spent most of their energies, a few of the more interesting types of marine engines will now be described.

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Nobel Diesel Marine Engines, Four-Stroke.

To Nobels must be given the credit of having built the first marine Diesel engine having variable speed, as previous to 1903, when this engine was built, only a small 20 b.h.p. engine had been fitted into a canal barge in France. Two engines of this type were fitted into the motor-tanker "Ssarmat" in 1904. They had four cylinders, each with a diameter of 320 mm. ($12\frac{5}{8}$ in.) and a stroke of 420 mm. ($16\frac{9}{16}$ in.), and were of the A-frame trunk-piston type, Fig. 3. The power developed in each engine was 180 b.h.p. at 240 r.p.m.

The "Ssarmat" was built for the Nobel Brothers Petroleum Production Co. at the Ssormovo Shipyard, on the River Volga, and had a deadweight capacity of 800 tons. Her hull dimensions were:—Length between perpendiculars, 244 feet 6 inches; breadth moulded, 31 feet 9 inches; and draught fully loaded, 6 feet. A sister ship to the "Ssarmat," named "Vandal," was built in the Ssormovo yard previously, but was fitted with four-stroke Diesel engines of the ordinary stationary type, the drive being purely Diesel electric.

The engines of the "Ssarmat" were non-reversible, the astern motion for the propeller shaft being obtained on the Del Proposto system, which consisted of a generator direct coupled to the engine shaft and an electro-motor coupled to the propeller shaft, with a friction clutch between them. For ahead running, the clutch was coupled in and the propeller was driven direct by the engine, the speed of the ship being regulated by the speed of the engine. Astern running was obtained by releasing the clutch, switching on the current, and the electro-motor turned the propeller in the astern direction. The "Ssarmat" has been in commission for 22 years, and still has the original engines.

The "Vandal" and the "Ssarmat" were the first motor-ships in the world, and although comparatively little publicity was given to their performance, it must be said that they

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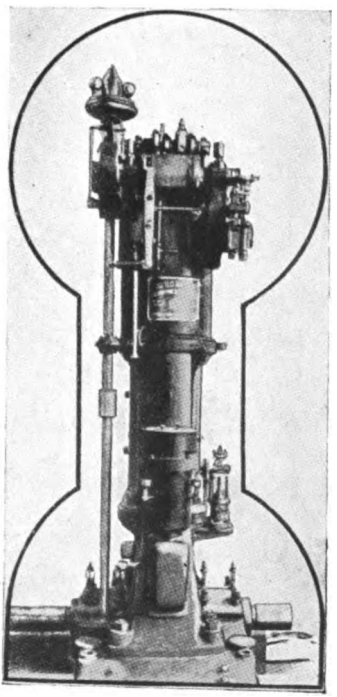

Fig. 1.—The first Nobel Diesel Engine, 1898.

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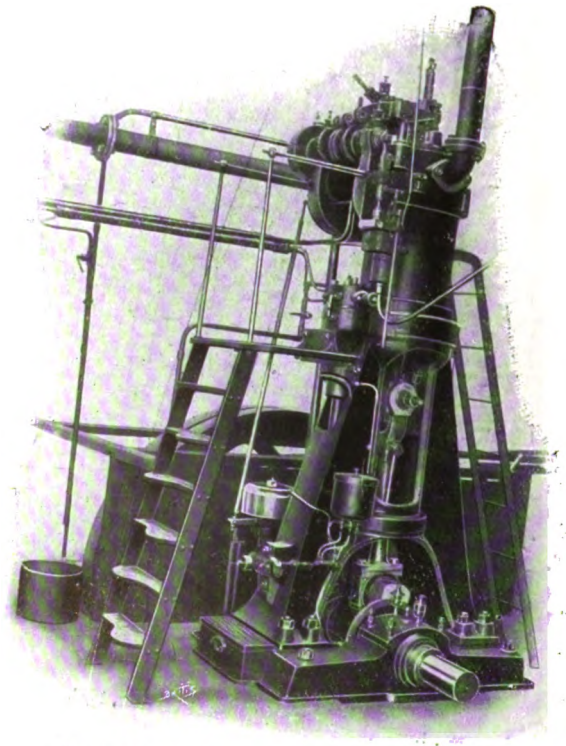

Fig. 2.—The first British Diesel Engine, 1897.

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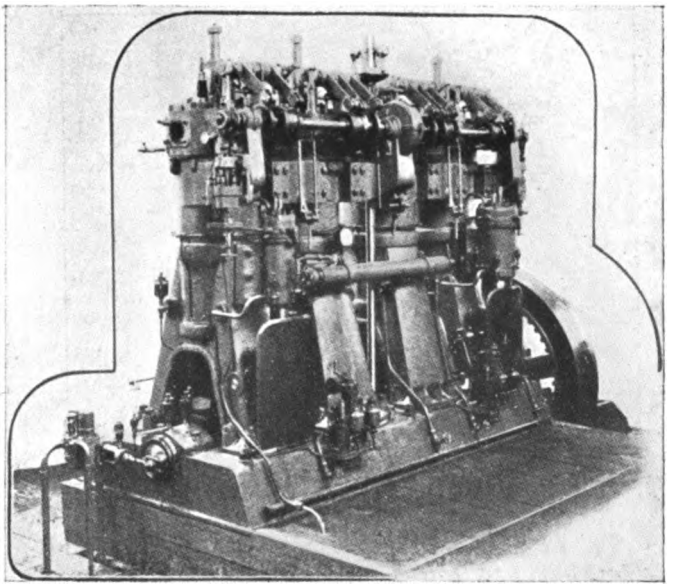

Fig. 3.—The first Marine Diesel Engine, 1903, of the Motor-Ship "Ssarmat."

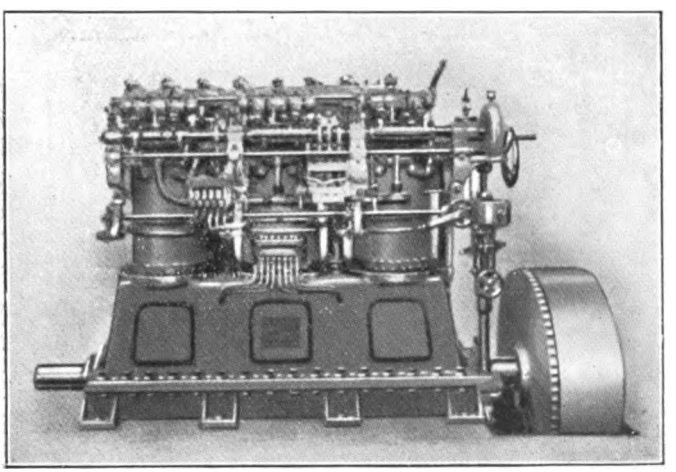

Fig. 4.—The first Four-Stroke Reversible Diesel Engine, 1907.

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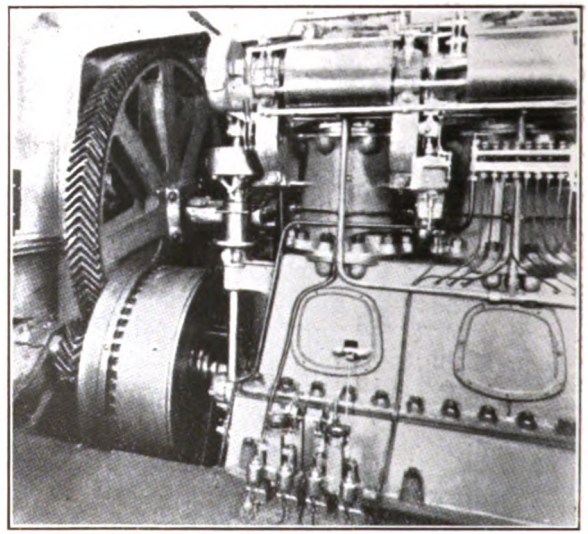

Fig. 5.—Citroen Gear Drive for Paddles, on Motor-Tug "Ssamoyed."

Fig 6.—Motor-Tug "Mazur."

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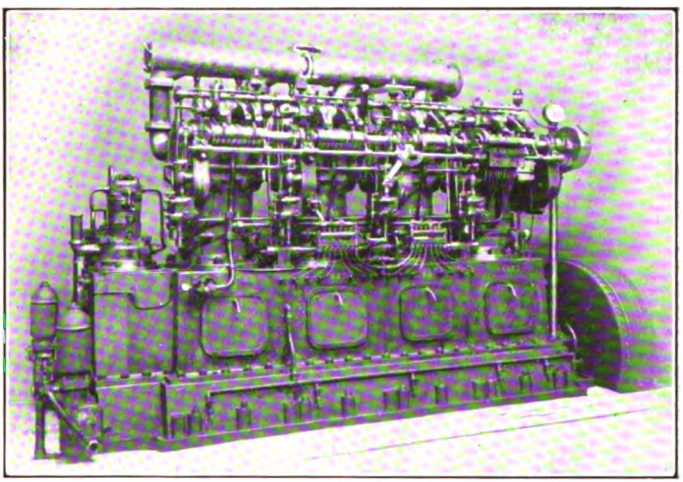

Fig. 7.—200 b.h.p. Nobel Diesel Engine of Motor-Tug "Mazur."

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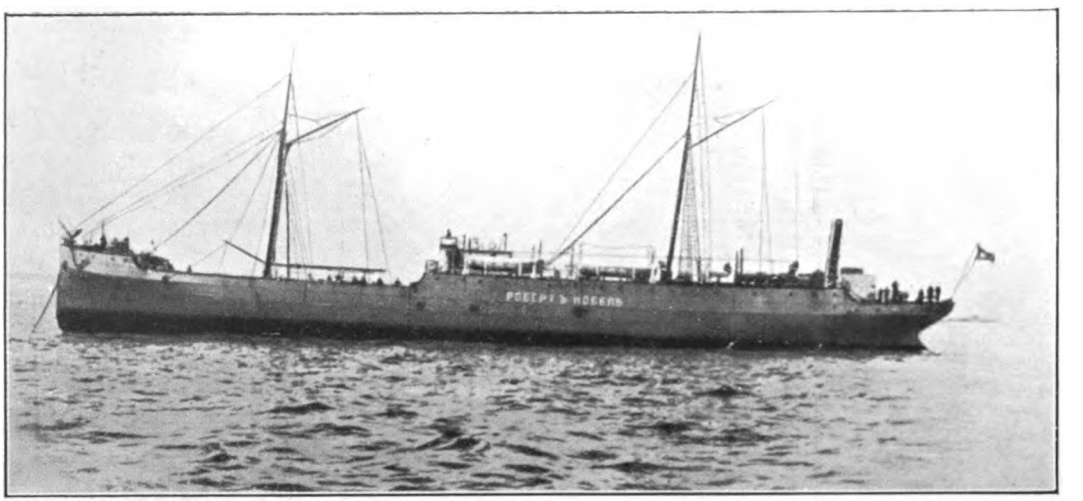

Fig. 8.—Motor-Ship "Robert Nobel."

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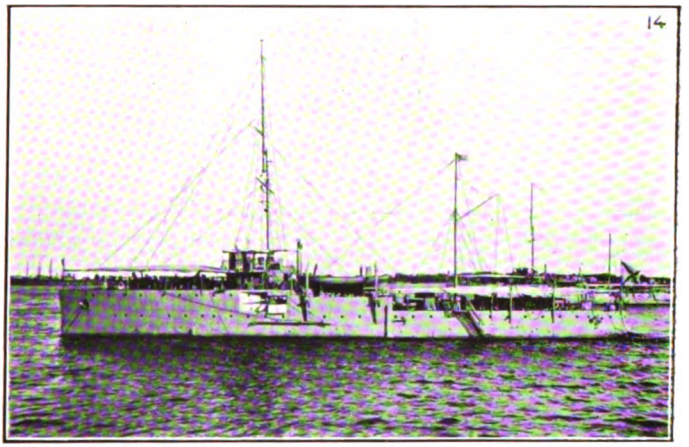

Fig. 9.—Motor-Gunboat "Ardagan."

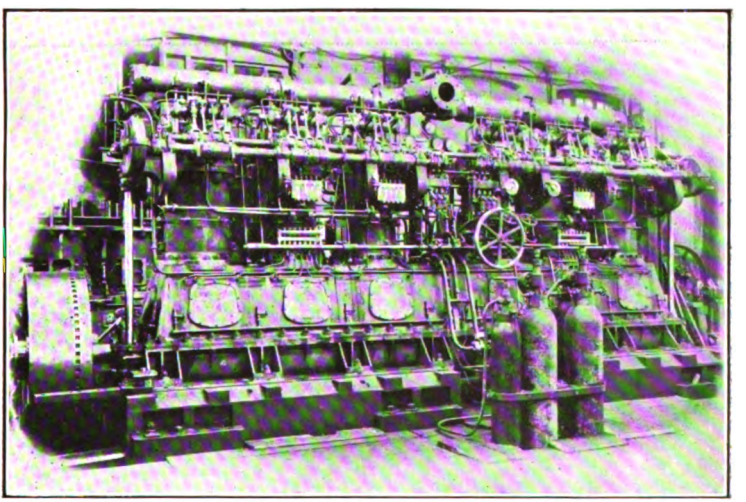

Fig. 10.—Port Engine of Motor-Gunboat "Kars."

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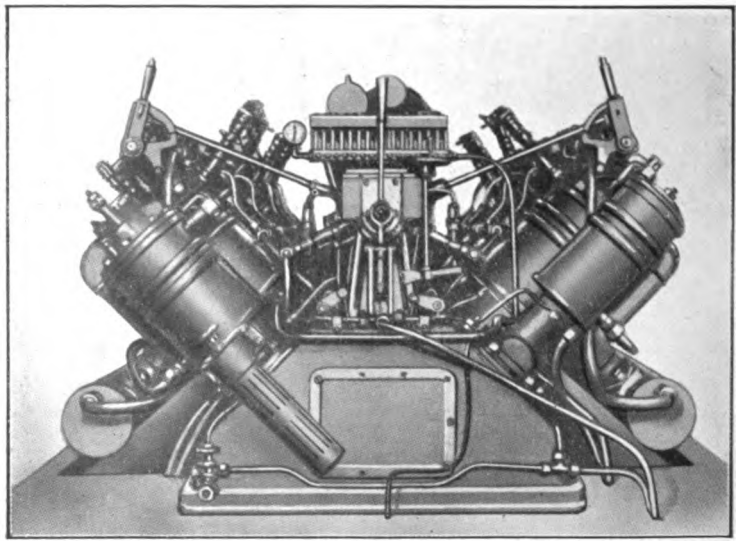

Fig. 11.—200 b.h.p. Nobel Diesel Engine of Motor-Yacht "Intermezzo."

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played a very important part in the development of motor shipbuilding in Russia. The performance of these ships was closely watched, and the fact that motor-ships in those days could maintain a regular service of over 3,000 miles, year in and year out, carrying petroleum in bulk, set many Russian shipowners thinking. This led the Nobel Brothers Petroleum Production Co. to decide to convert the whole of their steam fleet into motor-ships, and as the tonnage of this fleet was over 650,000 deadweight capacity, including tankers of 10,000 tons deadweight, it was a decision of very considerable importance. It was expected that the conversion would have been completed by 1924, but the outbreak of war, and later the Russian revolution, completely upset the programme, and finally the Soviet Republic "nationalised" the Nobel fleet, with the result that only a few small tankers are running at present. A part of the programme was carried out, starting with tugs and small tankers. The bulk of the engines were supplied by the Nobel works and their licencees in Russia, a few ships being fitted with engines purchased abroad. In the case of the paddle-tugs, it was necessary to introduce reduction gear, and for use in conjunction with this gear a special type of high-speed light multi-cylinder direct-reversible engine was designed for the purpose. The engine, Fig. 4, was the first direct-reversible four-stroke Diesel engine in the world, and developed 120 b.h.p. at 400 r.p.m. with cylinders of 275 mm. ($10\frac{13}{16}$ in.) diameter and 300 mm. ($11\frac{13}{16}$ in.) stroke. The type of reversing gear employed is known as Carlsund's. The cams were moved by means of forks fitted to a layshaft, and actuated by the hand-wheel seen in Fig. 4, near the top of the vertical shaft. Each cylinder had two sets of cams, and to allow them to be moved, the rocking levers for the valves had to be pressed down by means of the hand-lever seen on top of the engine, so as to lift the rollers clear of the cams. Two such engines were installed in the Russian submarine "Minoga" in 1908, which, although

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old as naval craft go, did very good work during the great war.

A number of these engines were built for naval purposes as well as for the mercantile marine, and in the non-reversible type as lighting sets in ships and stand-by engines in power stations. This type of engine was too small and of too high speed to work satisfactorily in the paddle-tugs, and a more powerful type was designed and developed, being later standardised in engines of three, four, and six cylinders. Besides river paddle-tugs, this type was fitted, in 1909, in the Russian submarine "Akula" (three four-cylinder sets, each of 300 b.h.p. at 375 r.p.m.). In the case of larger tugs, two direct-reversible engines were fitted, driving the shafts through electro-magnetic clutches. A typical example of this class of motor-tug was the "Ssamoyed," built in 1900. The hull dimensions were:—Length between perpendiculars 132 feet 9 inches, breadth moulded 19 feet, depth moulded 8 feet 3 inches, draught 3 feet 3 inches, and cargo-towing capacity 3,200 tons. She had two three-cylinder reversible four-stroke engines, each developing 140 b.h.p. at 260 r.p.m., whereas the paddles turned at 35 r.p.m. The paddle shafts were separate, and driven through an electro-magnetic clutch, and the speed reduction was obtained through herring-bone gears of the Citroen type, Fig. 5. The cylinder dimensions of these engines were:—Diameter 330 mm. (13 in.) and stroke 380 mm. (15 in.). Several other tugs were engined, but reference will only be made to the "Mazur" type, 1911-12, Fig. 6. This type had a single engine of 200 b.h.p., Fig. 7, and was built for service on the Vistula, in Poland. These vessels were captured and used for army purposes by the Germans, but after the signing of the Versailles Treaty they were returned to their rightful owners, and are now still maintaining the service for which they were built.

Among the sea-going motor-tankers may be mentioned the "Robert Nobel," of the Nobel Brothers Petroleum Co., Fig. 8.

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She was originally a twin-screw tank steamer of 1,700 tons deadweight, with a length of 260 feet, breadth 34 feet, depth 17 feet, and draught 14 feet. In 1910 she was converted from a steamer to a motor-ship, two enclosed crankcase type of engines of 400 b.h.p. at 215 r.p.m. being installed. The engines had the following cylinder dimensions:—Diameter 450 mm. ($17\frac{3}{4}$ in.), and stroke 510 mm. ($20\frac{1}{16}$ in.). The type of reversing gear employed on these engines is interesting, no movement of the cams being necessary for reversing. The ahead and astern cams had separate rollers on links attached to the valve rocking-levers. By a suitable movement of these links, the proper roller was placed against its cam for the required direction of rotation. The double roller type is known as Nordstroëms reversing gear, but is not used at present by Nobels, who changed the design at that time, as it was thought cam shifting was only suitable for engines of small power. All modern Nobel engines of large powers have hand cam shifting without any servo-motors being required, but the double roller type is employed by other builders of marine Diesel engines.

In the gunboats "Kars" and "Ardagan," Fig. 9, two 500 b.h.p. engines running at 310 r.p.m. were installed, and Nordstroëms reversing gear was employed. The cylinder dimensions were:—Diameter 375 mm. ($14\frac{3}{4}$ in.), stroke 430 mm. ($16\frac{15}{16}$ in.), and in general design these engines, Fig. 10, were very similar to those in the "Robert Nobel." An interesting point in these contracts was that Nobels had to instal these engines at their own risk, and in the case of failure to convert them to the non-reversible type with the Del Proposto drive. This was due to the fact that the other firms tendering refused to guarantee direct-reversing engines, and favoured the Del Proposto drive, which also appealed to the Russian Admiralty, as they had no experience of direct-reversing engines of this size. These gunboats had very successful trials in 1909, and the experience

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with them in service was also entirely satisfactory. They took part in military operations in the Caspian Sea in 1919. Two such engines were also fitted in the Revenue cruiser "Yastreb" in 1911, and one in the Admiralty icebreaker train ferry "Galerny." In 1909 the Russian Admiralty decided to replace all the petrol and paraffin engines in their submarines by Diesel engines. The weight of the former engines was from 20 to 25 kg. (45 to 55 lb.) per b.h.p., and the lightest marine Diesel engine at this time was about 40 kg. (90 lb.) per b.h.p. Tenders were invited, and the most suitable engines submitted had a weight of from 25 to 30 kg. (55 to 65 lb.) per b.h.p., but unfortunately the overall dimensions put this engine out of the question. Special arrangements were made eventually with the Nobel works, and they undertook the conversion of the 14 submarines. This necessitated extensive experimental work to produce a Diesel engine of suitable weight and dimensions, but by using high-grade materials such as chrome and nickel steels, aluminium, etc., an engine approaching the practical solution of the problem was produced. This engine, Fig. 11, was of the V-type, having eight cylinders each of 200 mm. (7⅞ in.) diameter and 220 mm. (8$\frac{11}{16}$ in.) stroke, and developed 200 b.h.p. at 600 r.p.m. The total weight was only 2,000 kg., or 10 kg. (22 lb.) per b.h.p., which made it the lightest Diesel engine produced at that time. Very exhaustive trials took place in the shops, after which the engine was fitted in the motor-yacht "Intermezzo" and tested under sea-going conditions, with the result that very valuable experience was obtained. Many points of this design were embodied in the engines specially built for the conversion of the 14 submarines, which required three entirely different types of engine, with powers of 120, 160, and 200 b.h.p. Time and space do not permit me to give a detailed description of these and other submarine engines built by the Nobel Co.

Another interesting conversion was that of the small cruiser "Rynda." The drive adopted in this case was purely Diesel-

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electric, as the Admiralty at the time when the order was placed (1910) had some doubts regarding the advisability of having reversible engines of 1,000 b.h.p., which, however, was contrary to the Nobel ideas. In view of the fact that a direct drive would involve too many alterations to the engine-room, the Nobel Co. agreed to the wishes of the Admiralty.

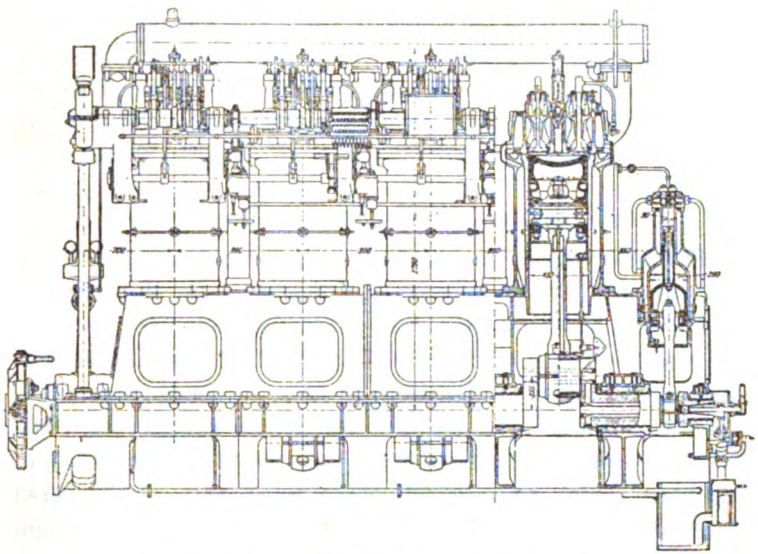

Fig. 12.—600 b.h.p. Nobel Diesel Engine of Cruiser "Rynda."

Eventually two high-speed engines, Fig. 12, were installed, similar to those in the "Robert Nobel," but their piston speed was increased to 5·45 metres per second (1,070 feet per minute), or 320 r.p.m., in order to obtain the necessary power output. The cylinder dimensions were:—Diameter 450 mm. ($17\frac{3}{4}$ in.) and stroke 510 mm. ($20\frac{1}{16}$ in.). With the adoption of the Diesel-electric drive the question of weight had to be seriously considered, and to reduce the total weight the main cast parts of the engine were made of steel, with the exception of the cylinder liners and pistons, which were of cast-iron.

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Fly-wheels were also dispensed with, as the armature of the dynamo, weighing 4,850 kg. ($4\frac{3}{4}$ tons), served as such.

The last type of four-stroke engine built by the Nobel Co. was as shown in Fig. 13, all the new engines being of the two-stroke type. Two such engines were installed in each of four Russian battleships, and were coupled to 320 kw. generators, supplying power for the various installations on ships of this class. The cylinders were :—Diameter 375 mm. ($14\frac{3}{4}$ in.) and stroke 430 mm. ($16\frac{15}{16}$ in.), the normal output being 480 b.h.p. at 320 r.p.m., which was obtained in six cylinders. The fuel consumption was 195 grams (0·43 lb.) per b.h.p. per hour.

Nobel Diesel Marine Engines, Two-Stroke.

The small two-stroke hot-bulb engine, previously referred to, was used for projector lighting sets in the Russian artillery, and, from the experience gained and valuable information obtained, the first Nobel Diesel two-stroke engine, Fig. 14, was designed in 1902. This engine underwent an exhaustive series of tests in the summer of 1903. The fuel consumption was 215 grams (0·474 lb.) per b.h.p. per hour at full load, which was very good, and compared favourably with the four-stroke Diesel engine of similar dimensions and piston speed. The cylinder diameter was 185 mm. ($7\frac{5}{16}$ in.) and stroke 290 mm. ($11\frac{7}{16}$ in.), and it developed 20 b.h.p. at 300 r.p.m., giving a brake m.e.p. of 3·85 kg./cm.^{2} (54·7 lb./in.^{2}), but on various overload tests developed 23 b.h.p. at 300 r.p.m. with a brake m.e.p. of 4·43 kg./cm.^{2} (63 lb./in.^{2}). This engine was installed in one of the Nobel munition factories during the Russo-Japanese war, and performed its duty there for three years, working ten hours daily. During this period the opportunity was taken of studying its behaviour and defects, but, considering the novelty of the design at the time, comparatively little trouble was experienced with it. Crankcase compression was employed,

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with scavenging ports placed all round the lower part of the cylinder, and the exhaust valves were in the cover. This engine was ultimately presented to the Petrograd Institute of Technology for experimental purposes. By this time the Nobel Co. had decided to adopt direct-reversing two-stroke engines for marine propulsion, as from a commercial point of view the Del Proposto system was too heavy and complicated, and, therefore, costly. A three-cylinder crank-case compression engine was, therefore, designed.

The first trial of the new engine took place in August, 1905; the reversing operation was found to take 18 seconds, and after many tests was proved to be entirely satisfactory. This engine was the first direct-reversible Diesel engine in the world, and, therefore, of particular historical interest. Many other novel features were embodied in the design besides the reversing gear, some of which were successful and adopted in later engines, while the others were naturally abandoned. Three cylinders, each of 260 mm. ($10\frac{1}{4}$ in.) diameter and 300 mm. ($11\frac{13}{16}$ in.) stroke were bolted to three separate crank-cases mounted on a common bedplate. The engine (similar to Fig. 15, but with separate crankcases) was rated to develop 200 b.h.p. at 400 r.p.m., with a brake m.e.p. of 4·73 kg./cm.^{2} (67 lb./in.^{2}). Instead of automatic valves in the crankcase, there were slots in the lower part of the cylinder which connected the inside of the crankcase with the atmospheric air when the lower part of the piston skirt uncovered these slots. This arrangement, although being simple mechanically, had the inherent drawback of all ordinary crankcase compression engines of starving the cylinder of air, with the result that a brake m.e.p. of only 3·3 kg./cm.^{2} (47 lb./in.^{2}) was obtained, which corresponds to 140 b.h.p. at 400 r.p.m. The separate crankcase design did not give sufficient rigidity owing to the light scantlings of the boats into which these engines were to be installed; therefore, a one-unit totally enclosed crankcase design was adopted, as shown in Fig. 15. The cast-

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iron cylinder heads contained two exhaust valves, fuel, starting, and safety valves. Forced lubrication was used for the cylinders, compressor, and for the main bearings, which were water cooled. The crankpin bearings were lubricated by banjo rings. The exhaust valves were uncooled, and consequently considerable trouble was experienced, due to the overheating of these valves. Severe heat-stresses were set up owing to the complicated casting of the cylinder head, which resulted in cracks developing. The reversing gear was Carlsund's, which has been previously described. A special feature in this engine was that the cylinders could be put on starting air by placing the master lever in a suitable notch, and then one by one on fuel.

As far as the two-stroke cycle part of the engine went, it was a failure, but the reversing gear and other details proved to be successful. It was evident, however, that it was undesirable to have exhaust valves in the head, and that probably scavenging valves in the head and the exhaust through ports in the cylinder would be more successful.

In 1909, the Russian Admiralty issued a specification for light compact submarine-engines in which the weight specified was 25 kg. (55 lb.) per b.h.p. to develop 300 and 400 b.h.p. Nobels produced an entirely new type of engine, Fig. 16, for this purpose, having valve scavenging and developing 350 b.h.p. at 400 r.p.m. The total weight of the engine, including the fly-wheel and all accessories, was 25·7 kg. (57 lb.) per b.h.p. There were six cylinders having diameters of 250 mm. ($9\frac{7}{8}$ in.), and the stroke was 300 mm. ($11\frac{13}{16}$ in.), giving a brake m.e.p. of 4·45 kg./cm.^{2} (63·2 lb./in.^{2}). The air compressor and the scavenging pump were driven direct from the crankshaft. These are the principal points, but there are some others which are worthy of comment.

The cylinder liners were suspended from the heads and were surrounded by water jackets which had special means provided for expansion, Fig. 17. The cast-steel cylinder

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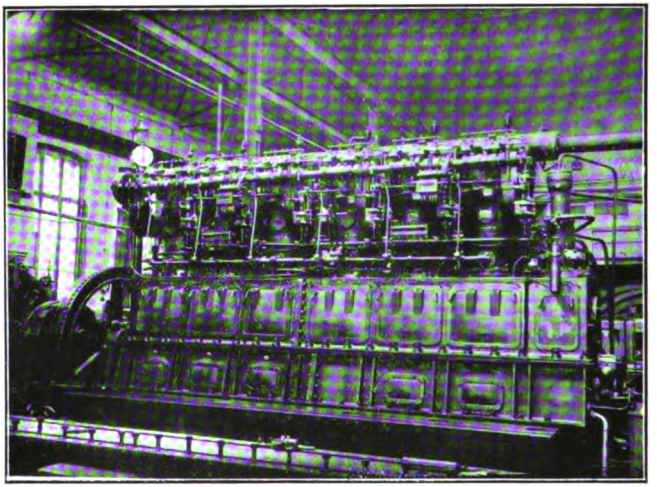

Fig. 13.—480 b.h.p. Nobel Diesel Engine of Battleship "Sebastopol."

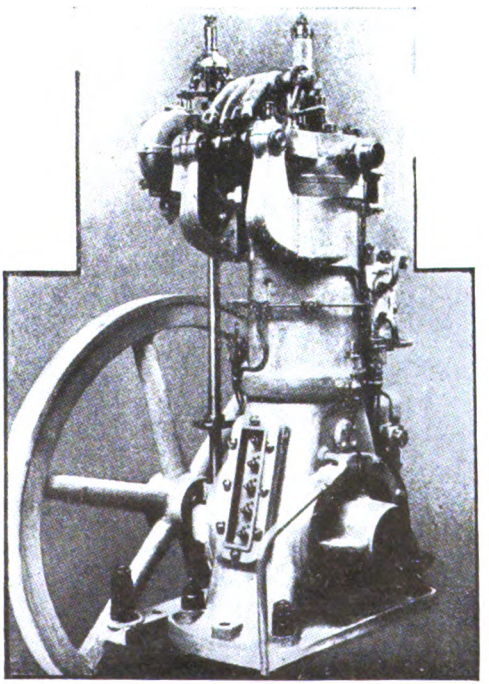

Fig. 14.—The first Two-Stroke Nobel Diesel Engine, 1903.

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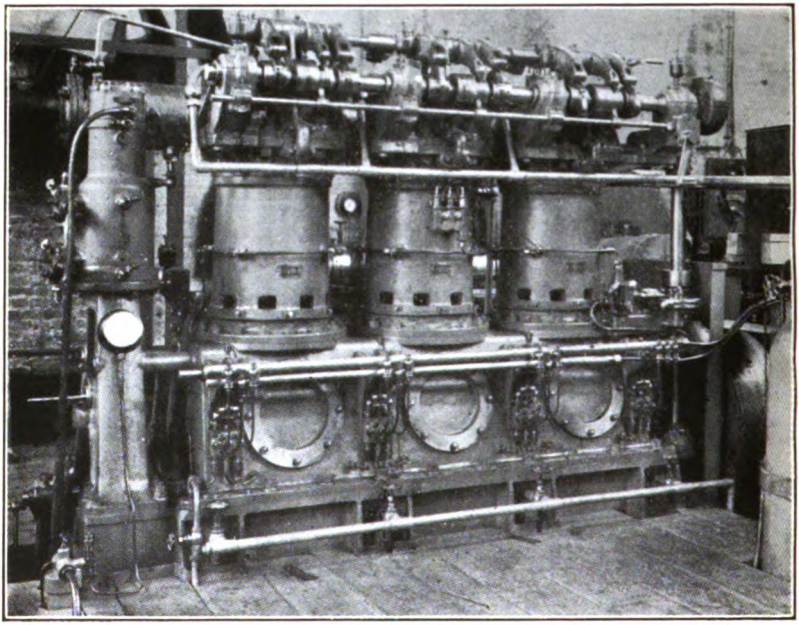

Fig 15.—The first Reversible Two-Stroke Engine, 1905.

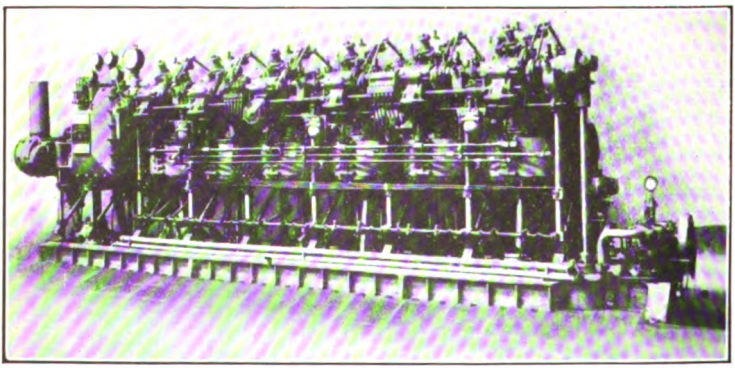

Fig. 16.—350 b.h.p. Nobel Diesel Engine of the Motor Yacht "Gradustchy."

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heads were supported by steel rods which took the tension stresses, and transverse diagonal rods were introduced between these to give rigidity, which was further increased by bolting the covers together to form a solid entablature.

The pistons (which were oil cooled) could be withdrawn downwards, and the exhaust gases were expelled through

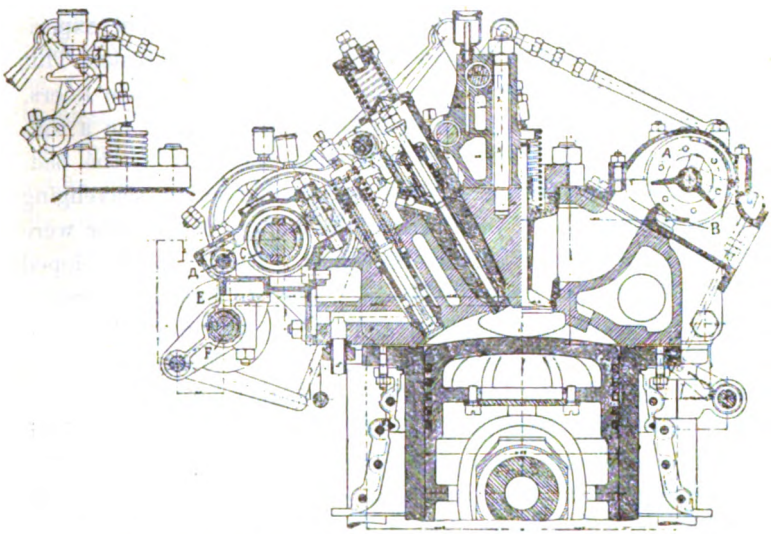

Fig. 17.—Valve Gear of 350 b.h.p. Two-Stroke Nobel Diesel Engine.

ports all round the bottom of the liners. All the valves in the cylinder heads, with the exception of the starting valves, were working during the running of the engine, and it will be seen from Fig. 17 that the design of the head was rather complicated for a two-stroke engine. The design of the valve gear, no doubt, led to the adoption of the so-called "supercharge," as the scavenging valve cams were specially shaped to allow these valves to close after the exhaust ports were covered. The reversing gear was of the Carlsund type, and very similar to that embodied in all modern Nobel engines.

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The fuel consumption of this engine was 235 grams (0·52 lb.) per b.h.p. per hour.

This engine was installed in Mr. Ludwig Nobel's yacht "Gradustchy," and exhaustive trials were carried out. Although the trials proved satisfactory, it was decided that the design was rather complicated and the engine likely to give trouble with the naval crews then available for submarines. Nobels abandoned the design, and another experimental engine was built, and in 1912 was ready for tests. This engine had two cylinders cast in block, with separate liners, and cast-steel covers. The cylinders were mounted on a thin cast-iron crankcase, and through bolts anchored to the bedplate took the tension stresses. A double-acting scavenging pump with a piston valve and a three-stage compressor were driven from the end of the crankshaft. The b.h.p. developed was 450 at 320 r.p.m. The cylinder dimensions were:— Diameter 450 mm. (17¾ in.) and stroke 480 mm. (18⅞ in.). One of the main features was the adoption of controlled port scavenging, further developed by Nobels at a later date, but latterly automatic valves have been substituted for controlling the scavenging air to the cylinders. The scavenging ports were arranged round part of the circumference at the lower end of the liner, and in the remaining part at the same height were the exhaust ports. The design of the cylinder head was very much simpler than in previous types, there being only three valves, namely, fuel, starting, and decompression valve, and of these only the fuel valve was working while the engine was running. This engine proved entirely reliable and very satisfactory in every way under working conditions.

Using the experience gained from the engine just described, a large number of engines, as shown in Fig. 18, were designed and built between 1914 and 1918, and installed in all the Russian submarines of the "Kaguar" class. The eleven-throw crankshaft of these engines was supported in a

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cast-iron bedplate, and again a light crankcase was fitted, and through bolts supported the cylinders, also taking the tension stresses. The total b.h.p. of these engines was 1,360 at 350 r.p.m., or 170 b.h.p. per cylinder, with dimensions 390 mm. ($15\frac{3}{8}$ in.) diameter and 430 mm. ($16\frac{15}{16}$ in.) stroke. The details differed somewhat from the experimental engine, but the general design was the same. Two double-acting scavenging pumps were placed at the forward end, and the trunk guides of these acted as the L.P. stage of the compressor, the I.P. and H.P. stages being in tandem and driven by the foremost crank. The engines of the "Kaguar" were reversible, but the remaining engines were non-reversible, as the motors used for under-water propulsion served this purpose. The lubrication of this engine is interesting. The cylinders, gudgeon pins, and air compressors were supplied with oil under pressure, but the main bearings, which were water cooled, had a gravity feed, and the crankpins had centrifugal lubrication (banjo rings). This method proved entirely satisfactory, no bearing troubles being experienced in spite of the high speed of the engine. At full load the fuel consumption was 228 grams (0·504 lb.) per b.h.p.

Several smaller and larger engines of this type were developed. The former gave 550 b.h.p. at 350 r.p.m. in six cylinders, while the latter, which were to be fitted in the large Russian submarine twin-screw cruisers, had eight cylinders, each developing 312·5 b.h.p. at 250 r.p.m., or a total of 2,500 b.h.p.

Some high-power auxiliary sets were also built for the Russian battle cruisers of the "Navarin" class. In six cylinders these engines developed a total of 480 b.h.p. at 320 r.p.m., and were coupled to 320-kw. dynamos. The cylinder dimensions were:—Diameter 320 mm. ($12\frac{5}{8}$ in.) and stroke 350 mm. ($13\frac{3}{4}$ in.). Oil was the medium used for cooling the pistons, and the cylinders had sea-water cooling. Although these engines were of the crosshead type, one of the main

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features of the design was compactness. Their overall dimensions were:—Length (including a fly-wheel type dynamo) 7,750 mm. (25 ft. 5⅛ in.), width of bedplate 1,100 mm. (3 ft. 7⅜ in.), height (above floor) 2,940 mm. (9 ft. 7⅜ in.).

In 1917-18, several sets of the last three types described were under construction, but the Soviet Republic "nationalised" the Russian Nobel Works, and unfortunately their fate is unknown to the present Nobel Co.

Despite the handicap of war work, several successful commercial types of two-stroke engines were built. In 1915 the steamer "Imperatritza Alexandra" was converted to a motorship. The Kawkaz and Mercury Steamship Co. were the owners, and this twin-screw vessel maintained the mail service in the Caspian Sea between Baku and Krasnovodsk with a speed of 13 knots, on a displacement of 1,700 tons. The engines installed, Fig. 19, developed 600 b.h.p. each at 210 r.p.m., with the following cylinder dimensions:—Diameter 410 mm. (16⅛ in.), and stroke 500 mm. (19 11/16 in.). All auxiliaries in the ship were steam driven, the steam being obtained from a small oil-fired boiler. The oil burned under this boiler was first used for lubricating all the crankshaft bearings. These bearings were supplied with large quantities of this oil, which was afterwards pumped from the bed, filtered, and again used for the bearings, and so on until it became too thick, when it was burned under the boiler and the lubricating system supplied with fresh oil. This led to considerable economy in lubricating oil, the consumption in service being less than one per cent. of the amount of fuel used. At full load and normal speed the fuel consumption was 200 grams (0·44 lb.) per b.h.p. per hour.

The double-acting scavenging pump and main and auxiliary compressor were driven from the forward end of the crankshaft, Fig. 19. The scavenging pump, Fig. 20, had a rotary distributor running at one-third of the engine speed, and the scavenging ports to the cylinder, which were at the same

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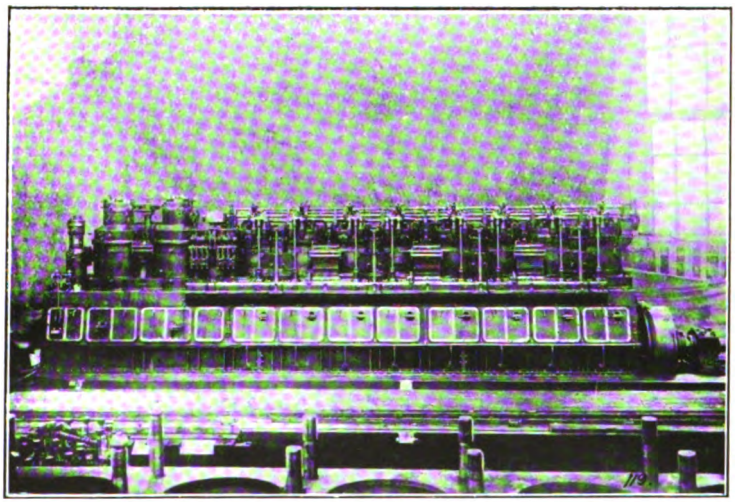

Fig. 18.—1,360 b.h.p. Nobel Diesel Engine of Submarine "Kaguar."

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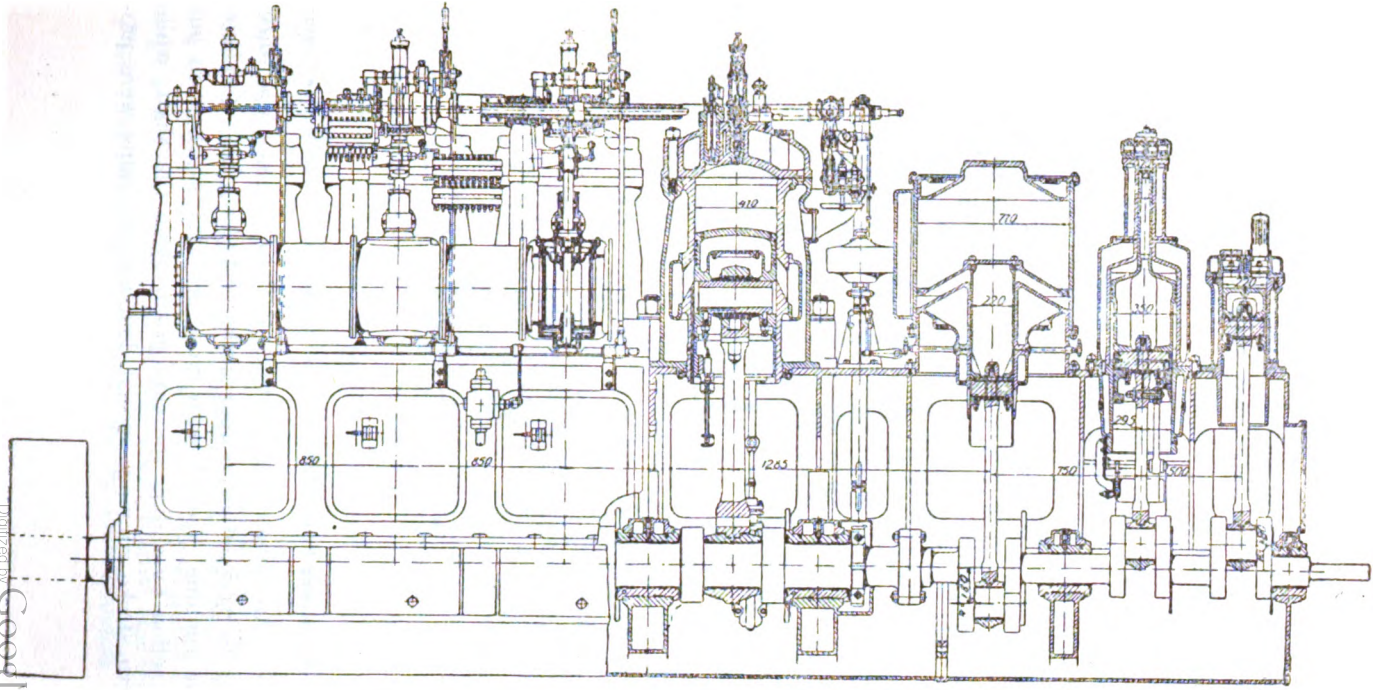

Fig. 19.—600 b.h.p. Two-Stroke Reversible Nobel Diesel Marine Engine.

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height as the exhaust ports and had the admission of air also controlled by rotary distributors, Fig. 19, were driven through bevel gears from the crankshaft at one-half the speed of the

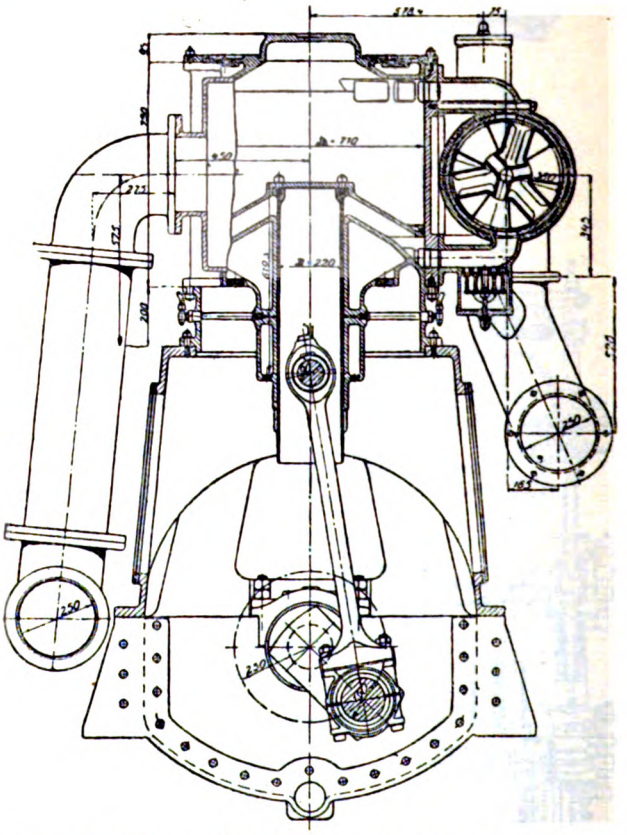

Fig. 20.—**Scavenging Pump of 600 b.h.p. Two-Stroke Nobel Diesel Marine Engine.**

engine. An outstanding feature of these engines was their ability to work either as four-stroke or two-stroke. For four-stroke running, special cams were provided which were put into action by sliding the cam group along the shaft, while for two-stroke running, special double-nosed cams were pro-

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vided. Each group of cams was mounted on a sliding sleeve which could be moved along the hollow camshaft by a rod inside the latter connected to the reversing lever. For slow running, four-stroke working was considered particularly suitable, as it was thought that on the two-stroke cycle, when running slow, the minute quantities of oil injected would cause misfiring, and, therefore, unsteady running of the engines. However, the two-stroke working at slow speeds was entirely satisfactory, and in other engines of this type the four-stroke complication was abandoned. The manœuvring gear for the two engines was placed on the upper platform, Fig. 21, each engine having three levers, namely, starting, reversing, and fuel. The stop valves of the air bottles were placed behind these levers, but to avoid constant operation of these valves when manœuvring, special valves were arranged, actuated by the starting lever. Only one man was required for handling both engines.

In 1916, the demand for slow-speed heavy-duty engines for cargo ships became acute. In view of this Nobels designed and built a six-cylinder 1,500 b.h.p. two-stroke marine Diesel engine running at 150 r.p.m. The cylinder dimensions were:— Diameter 560 mm. ($22\frac{1}{16}$ in.) and stroke 700 mm. ($27\frac{1}{2}$ in.). All ports in the cylinders were at the same height, and the scavenging ports were controlled by piston valves. Both the scavenging pumps and the air compressors were arranged at the back of the engine, and driven by rocking levers and links from the crossheads.

The Russian revolution caused the dispersal of the staff of Ludwig Nobel, Ltd., who nearly all left the country. However, in the summer of 1918, Mr. Ludwig Nobel managed to collect most of his old engineers and foremen together, and formed a new company at Nynäshamn, in Sweden. This company acquired some existing works and concentrated their energies on the development of slow-speed marine engines.

Their first large engine was one having four cylinders and

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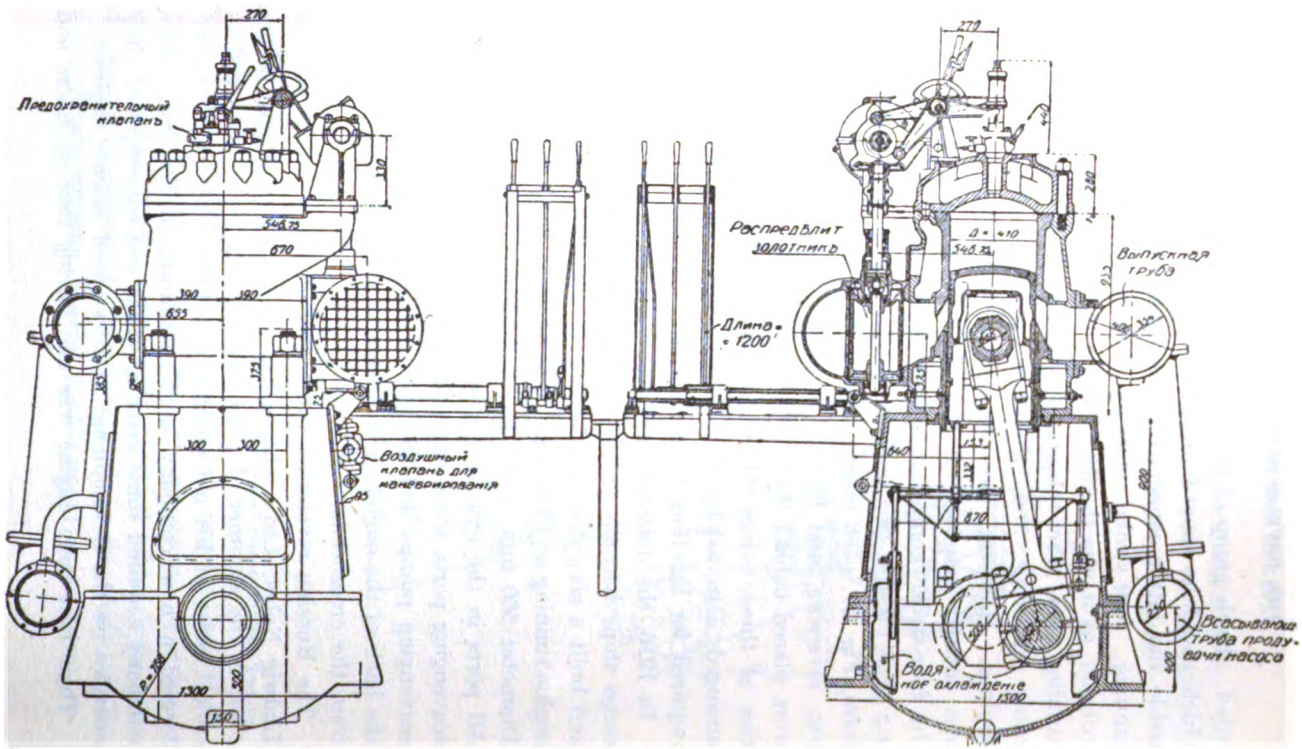

Fig. 21.—View showing relative position of Nobel Diesel Engines in Motor-Ship "Imperatritza Alexandra."

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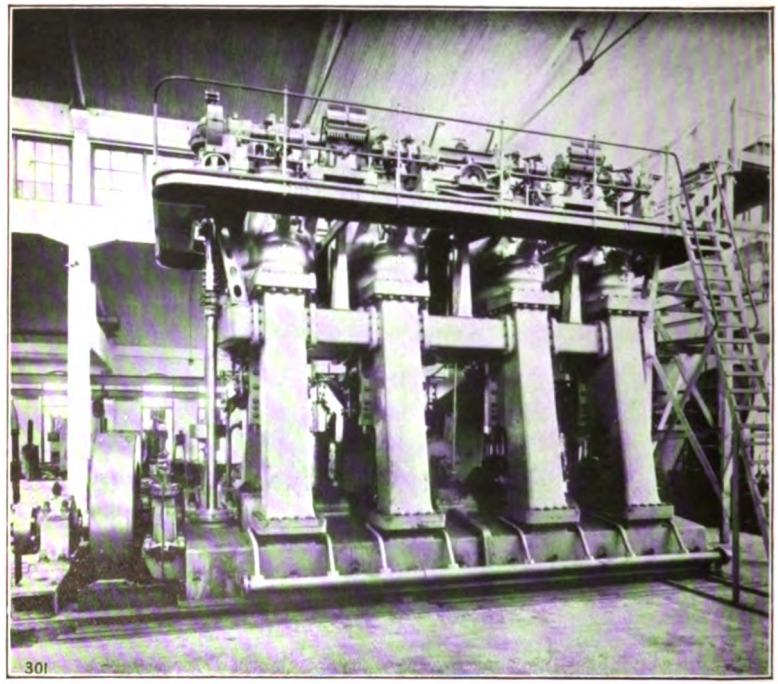

Fig. 22.—1,600 b.h.p. Nobel Diesel Two-Stroke Marine Engine.

Fig. 23.—The Motor Tanker "Zoroaster."

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developed 1,600 b.h.p., or 400 b.h.p. per cylinder, at a speed of 105 r.p.m., Fig. 22. The cylinder dimensions were:— Diameter 675 mm. (26½ in.) and stroke 920 mm. (36¼ in.).

In some tests made on this engine by Prof. Anders Rosborg, of Stockholm University, the mechanical efficiency was 81 per cent. at full load, which, in view of the fact that the scavenging pumps and air compressors were driven by the engine, is highly satisfactory. The fuel consumption was 180 grams (0·397 lb.) per b.h.p. at full load (lower calorific value of oil 9,960 cal./kg.). One feature of particular interest in these tests was the experience gained regarding supercharge (scavenging ports higher than exhaust ports), it being found that this had no particular advantage over having the ports at equal height, *i.e.*, without supercharge. Considerable economy of starting air was obtained by using a decompression valve in each cylinder, and by taking the air which normally would be compressed to the scavenging air receiver during starting and manœuvring. This arrangement had the further advantage of raising the pressure in the receiver to normal, and, therefore, the compression pressure was normal when the engine was put on fuel. The admission of scavenging air to the cylinder was controlled by piston valves, driven from the camshaft, but at a later date, after further experience had been gained in service, automatic valves were substituted.

This engine was installed in the tanker "Zoroaster," Fig. 23,* the completion of which was considerably delayed owing to the late delivery of plates from Germany. The principal dimensions of the vessel were:—

Length, between perpendiculars	-	309 feet	9 inches.
Breadth, moulded - - - -		49 ,,	0 ,,
Depth, moulded - - - -		28 ,,	0 ,,
Load draught - - - -		22 ,,	4 ,,

* For details of engine see The Engineer of 27th Jan. and 3rd Feb., 1922, and for the machinery arrangement see The Motor Ship, April, 1923.

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Deadweight capacity	5,400 tons.
B.H.P. 1,600	I.H.P. 2,000.
Designed speed	11 knots (trial).

After successful trials in March, 1924, the vessel was handed over to the owners, and started on her maiden voyage on April 9th. By the 30th March, 1925, after nearly one year's service, the "Zoroaster" had covered a distance of 60,603 nautical miles, and the voyages undertaken occupied 293 days. An average speed of 9·5 knots was maintained throughout this period, although exceptionally stormy weather was experienced during several of the voyages.

During the fifth voyage (Vigo-Gijon-Pasajes-Bilbao) proof of the easy manœuvring qualities and economy of starting air of the engine was obtained. When going up the river to Bilbao, 63 manœuvres were required, sometimes with only an interval of a few seconds, but all were carried out without the slightest hitch. A few figures regarding these features are given below.

MANŒUVRES LEAVING GIJON FOR PASAJES, 2ND JULY, 1924.

Time.		Starting air pressure. Atmospheres.
1.20 p.m.	Stand by	24·2 (7 cub. m.).
1.35 „	Half astern	22
1.40 „	Full ahead	20
1.43 „	Stop	
1.46 „	Full ahead	19
1.48 „	Full astern	18
1.50 „	Full ahead	17
1.51 „	Full astern	16·5
Tank recharged	From stand-by tank to	20·8
1.53 p.m.	Slow ahead	20
1.55 „	Stop	
1.57 „	Full astern	18·6
1.58 „	Full ahead	17·5
1.59 „	Slow ahead	
2.0 „	Stop	
2.1 „	Slow ahead	16·5
2.2 „	Full ahead	

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TIME TAKEN FOR EACH MANŒUVRE ENTERING HARBOUR AT PASAJES.

		Seconds.
8.24 a.m.	Stop	
8.24·2 „	Full astern	8½
8.25 „	Stop	
8.27 „	Slow ahead	7
8.31 „	Stop	
8.31·25 „	Slow astern	6
8.31·5 „	Stop	
8.34 „	Full ahead	11½
8.37 „	Stop	
8.37·1 „	Full astern	12
8.38 „	Slow astern	
8.39 „	Stop	
8.42 „	Slow ahead	10½
8.43 „	Stop	
9.0 „	Slow astern	7
9.1 „	Stop	
9.8 „	Finished	

Two starting-air receivers, each having 7 cubic metres capacity, were fitted, and when the pressure in one receiver fell below 12 atmospheres the auxiliary compressor (which had a capacity of 9 cubic metres of free air per minute to a pressure of 50 atmospheres) soon replenished it, the other receiver being used for the intervening manœuvres. Under ordinary conditions, however, these receivers could be replenished by the main engine compressor.

During the first two voyages, the mechanically-operated scavenging valves gave entire satisfaction, but experience with automatic valves was desired under actual service conditions, and these valves were, therefore, fitted. The principal advantage proved to be the simplifying of the reversing mechanism, and the engine could be operated with greater ease. The fuel consumption was the same with both arrangements.

In Figs. 24 and 25, light spring diagrams are given, which show the difference between the working of the automatic and mechanical scavenging control. The automatic valves adapt

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themselves to various loads, whereas mechanical appliances can only be adjusted properly for one particular power, usually full load. The diagram taken from a cylinder with a mechanically-operated valve is shown in Fig. 24, and it will be noted that at the closing of the scavenging ports, or at the beginning of the actual compression, the pressure is 0·114

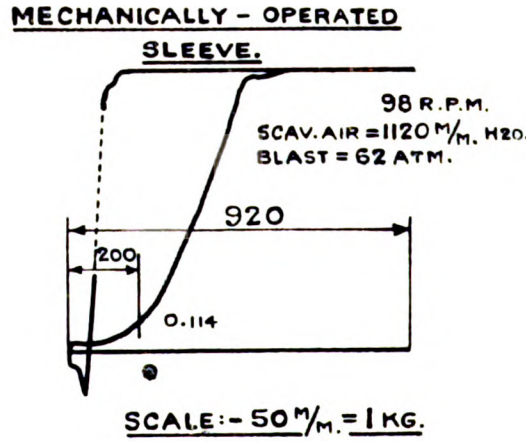

Fig. 24.—Mechanically-Operated Sleeve.

atmosphere, which is about the same as the scavenging air pressure.

Fig. 25 shows a diagram taken with the automatic scavenging valve, and it will be noted that the initial pressure is about 0·2 atmosphere when the compression begins. It thus appears that, after scavenging and filling the cylinder, the upward stroke of the piston produces a higher pressure in the cylinder than in the scavenging-air receiver, and the automatic valve closes, preventing any return of air to the receiver. In the case of the mechanically-operated sleeve, the cylinder remains in connection with the receiver until the piston covers the ports, and, therefore, the air in the cylinder is free to flow back to the receiver.

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Indicator cards taken during the voyages showed a normal form, and typical cards for full, half, and slow speed of the ship are given in Fig. 26. The rise in pressure due to combustion generally amounts to from 15 to 20 per cent. The engine speed can be reduced to 28 r.p.m. without showing any inclination to stop.

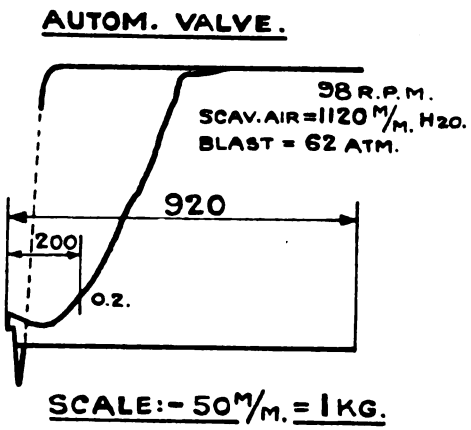

Fig. 25.—Automatic Valve.

Figs. 27, 28, and 29 show illustrations from photographs taken in the engine-room of the "Zoroaster" when in a British port.

The Nobel engine is now being manufactured under licence by the following firms:—

1. Mirrless, Bickerton & Day, Ltd., Stockport.
2. Burgerhout Engineering and Shipbuilding Co., Rotterdam.
3. The Niigata Engineering Works, Tokyo, Japan.
4. Nydqvist & Holm, Trollhättan, Sweden.

The following are the principal dimensions of an engine of the Nobel type manufactured by the Burgerhout Co., which was tested in their works under the supervision of Prof. P.

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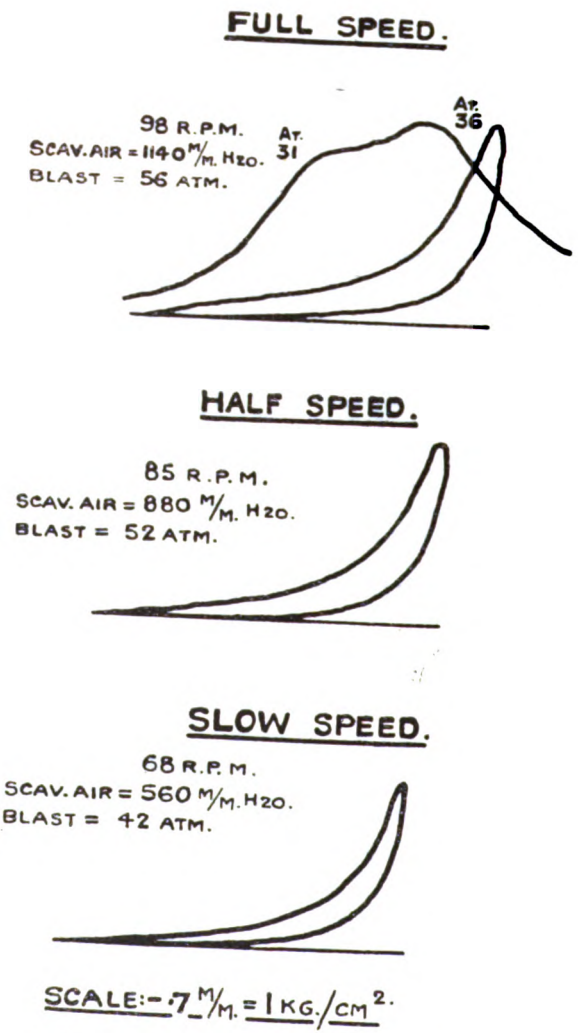

Fig. 26.—Typical Indicator Cards from Engine of Motor-Ship "Zoroaster."

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Meyer, of the Technical High School, Delft, in February, 1925.

	Diameter.		Stroke.	
	Milli-metres.	Inches (approx.)	Milli-metres.	Inches (approx.)
Cylinders	530	21	950	37½
Scavenging pump	720	28¼	720	28¼
L.P. Compressor (Annular)	430/90	17/3½	630	24¾
I.P. Compressor	200	8	630	24¾
H.P. Compressor	90	3½	630	24¾
Cylinder circulating pumps	150	6	365	14⅜
Piston circulating pumps	150/125	6/5	365	14¾

Length over crankshaft: 6,100 mm. (21 ft. 3 ins.).
Width of bedplate: 3,000 mm. (10 ft.).
Maximum width over scavenging pumps: 4,250 mm. (13 ft. 11 ins.).
Weight of engine, excluding fly-wheel, but with all auxiliaries attached: 124,600 kg. (123 British tons).

This engine is shown on the test bed in Fig. 30, and the bedplate and crankshaft in Fig. 31. The full-load rating was 900 b.h.p. (75 kg.-m./sec.) at 95 r.p.m., with a brake m.e.p. of 5 kg./cm.² (71 lb./in.²). The fuel consumption at varying loads was taken during the tests which were of 174 hours' duration, and the results are given below.

	B.H.P.	Brake m.e.p. Atmos.	R.P.M.	Blast air. Atmos.	Scav-enging air. mm. H_2O.	Fuel consumption, kg. per B.H.P.-hour.
Twenty per cent. overload	1,084	5·96	97·7	59	570	·191 (·421 lb.)
Full load	903	5·01	96·7	56	565	·184 (·405 ,,)
Three-quarter load	681	3·75	97·5	50	570	·188 (·414 ,,)
Half load	453	2·49	97·8	44	610	·205 (·452 ,,)
One-quarter load	224	1·22	98·5	41	645	·276 (·608 ,,)

Fuel Oil—Specific gravity at 15 degrees C. = ·8624.
Calorific value = 10,300 kg. cal. (Lower value).

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Indicators were fitted to the scavenging pumps and to the air compressor, and the power absorbed by them recorded. The overall mechanical efficiency of the engine was 78·5 per cent. If the scavenging pumps were driven independently, this efficiency would be increased to 82·5 per cent., and if the air compressor also were driven separately, it would be further increased to 88 per cent.

These tests were duly accomplished, and with the exception of one stop to replace a broken compressor spring, they were entirely satisfactory. If an auxiliary compressor had been available, this stop would have been avoided. After the tests, the engine was opened up and all parts were found in good condition. Owing to a leaky needle-valve in No. 2 cylinder, a little carbonisation was noticeable on the piston of this cylinder, but all the piston rings were entirely free.

The Burgerhout Co. have recently completed an interesting conversion by installing the engine just described in the tanker "Black Sea," belonging to the British Black Sea Shipping and Oil Co., Ltd., of London. This vessel was previously a steam-tanker with triple-expansion machinery. Details of the conversion have appeared in the technical press.*

Some typical details of Nobel design are shown in Figs. 32, 33, and 34.

A Mirrlees-Nobel engine of 1,000 b.h.p. at 125 r.p.m. is shown in Fig. 35. This engine was manufactured by Mirrlees, Bickerton & Day, Ltd., Stockport, and was the first of the Nobel type to be manufactured in this country.

In general it follows the Nobel design, but the details have been modified in some respects to agree with the makers' methods of manufacture, based on their extensive experience in the manufacture of Diesel engines. The number of different components have been reduced to a minimum, in accordance with their views on the value of standardisation

* The Motor Ship, February, 1926.

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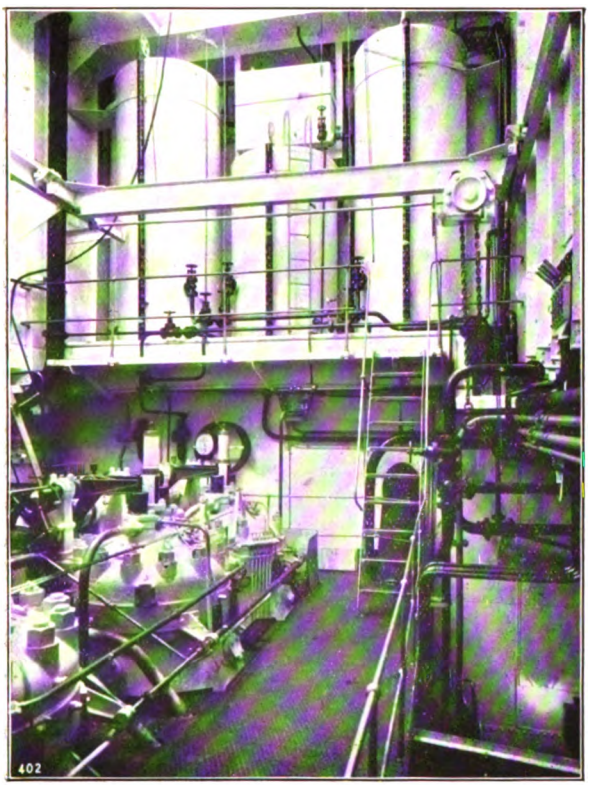

Fig. 27.—Cylinder Heads and Fuel Tanks.

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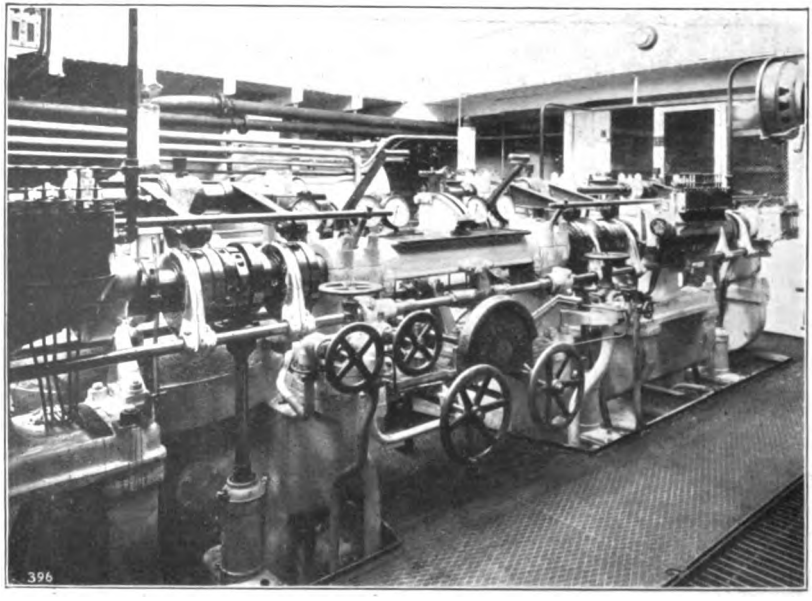

Fig. 28.—Reversing and Manœuvring Gear.

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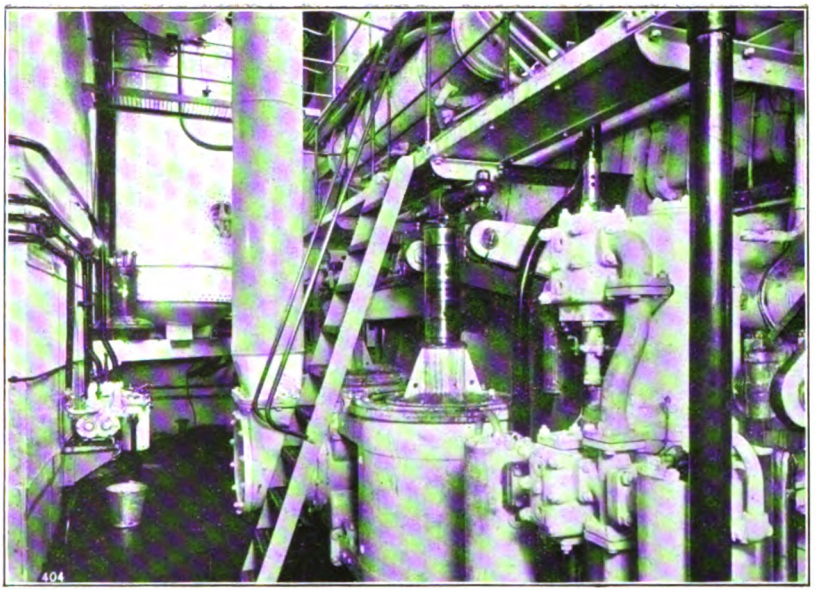

Fig. 29.—Back of Engine.

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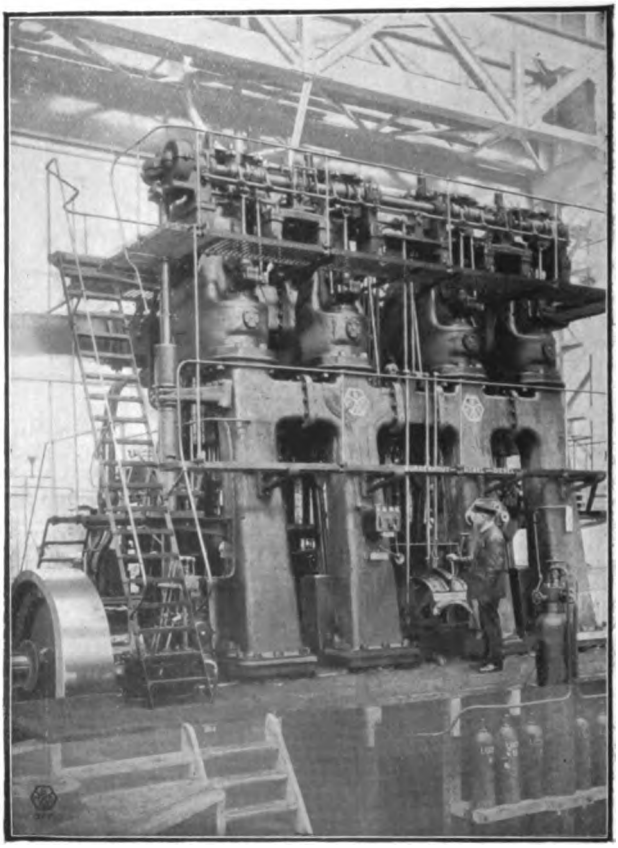

Fig. 30.—900 b.h.p. Burgerhout-Nobel Diesel Engine.

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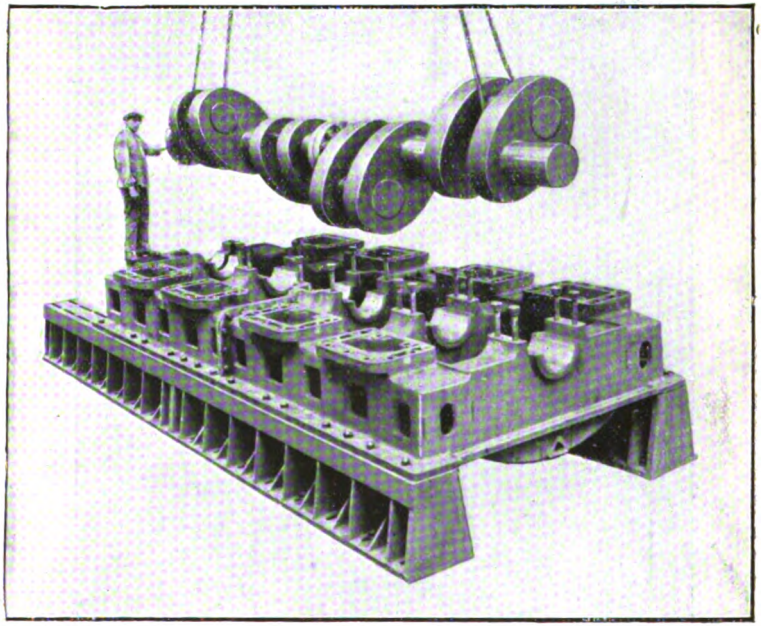

Fig. 31.—Bedplate and Crankshaft for 900 b.h.p. Engine.

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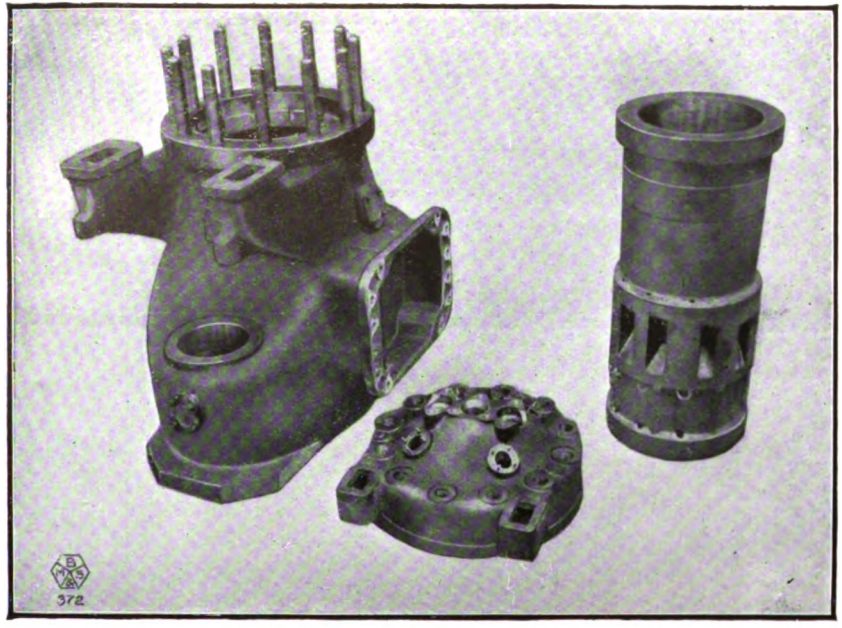

Fig. 32.—Cylinder, Cover, and Liner.

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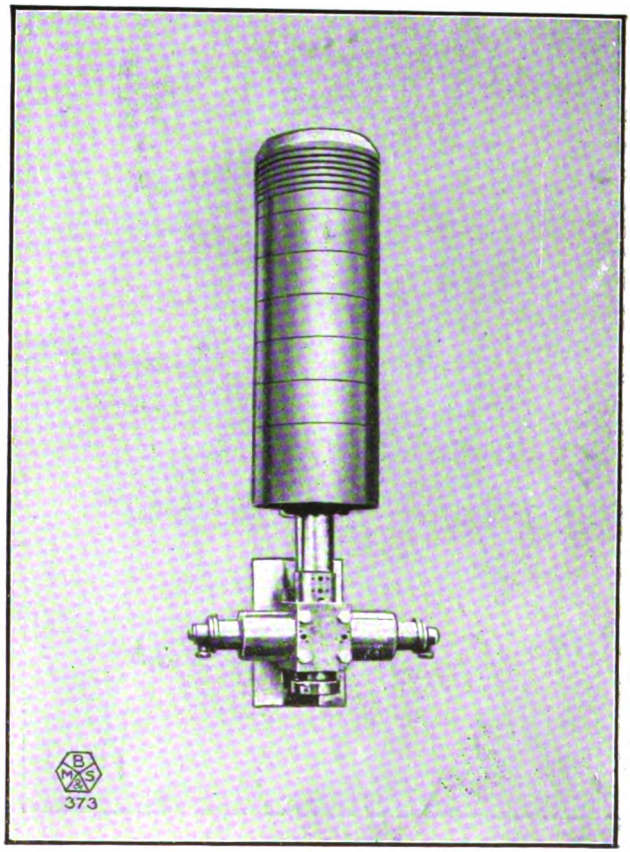

Fig. 33.—Piston and Crosshead.

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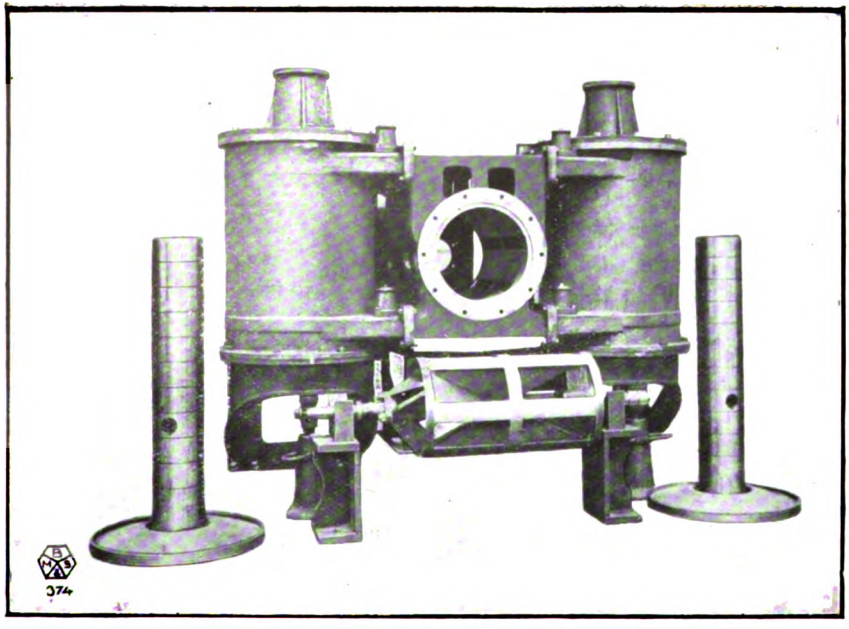

Fig. 34.—Scavenging Pumps, with Pistons and Distributor.

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and interchangeability of parts. An instance of this can be seen (Fig. 35) on the camshaft, which is in three pieces, coupled together by muff couplings. This permits of the cam

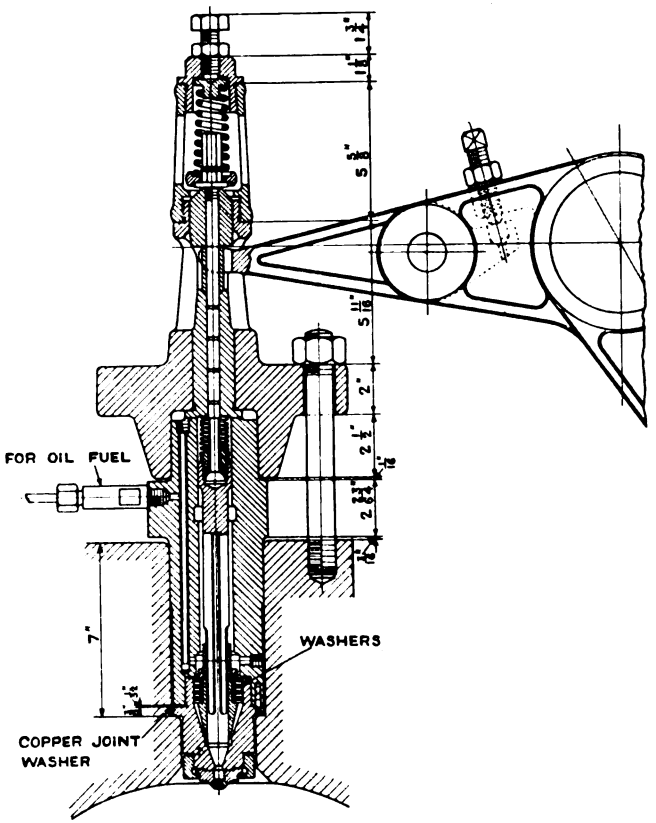

Fig. 36.—Packingless Fuel-Valve.

blocks being made exactly alike, as well as simplifying the manufacture. They have also embodied many details which they have perfected, the patent packingless fuel-valve shown in Fig. 36 being an example. It will be noted that the valve lever is jointed, and by unscrewing the set bolt, the end of

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the lever can be dropped clear of the valve. The starting and decompression valve levers have a similar joint; therefore any of these valves can be removed without dismantling all the levers and fulcrum shaft. The valve spindle is in two parts, joined by a ball and socket joint which removes the necessity of perfect alignment. Any tilting of the valve casing, caused by unequal tightening of nuts, will not affect the proper working of the valve. A valve face prevents any leakage past the upper part of the spindle.

The Mirrlees-Nobel engine is unique in so far as it embodies the experience of two firms who have been engaged in the manufacture of the Diesel engine since its inception.

It has been fully described recently in the technical press,* so a brief reference will only be made here to some of the principal features. The four cylinders are each 22 in. in diameter, with a stroke of 29½ in., and at 125 r.p.m. the corresponding piston speed is only 615 feet per minute. The main construction and arrangement are clearly shown in the sectional end elevation, Fig. 37, from which it will be noticed that, unlike the " Zoroaster " arrangement, the controls are taken to the bottom platform.

Figs. 38 and 39 show details of the piston-cooling arrangement. The cooling water is taken to the fitting in the crosshead through a link motion, Fig. 37, and from the crosshead to the annulus round the central or return pipe in the hollow piston rod. On reaching the top of the piston rod, the water circulates round the piston head, and it will be noticed that effective cooling of the piston crown is assured by carrying the return pipe close up to it. Fig. 38 also shows how provision is made for any difference in expansion between the skirt of the piston and the piston rod. The top of the skirt is only guided and free to expand, while at the lower end, where it is attached to the piston rod, provision is made for slight eccen-

* The Shipbuilder, Jan., 1926, and Engineering, 15th Jan., 1926.

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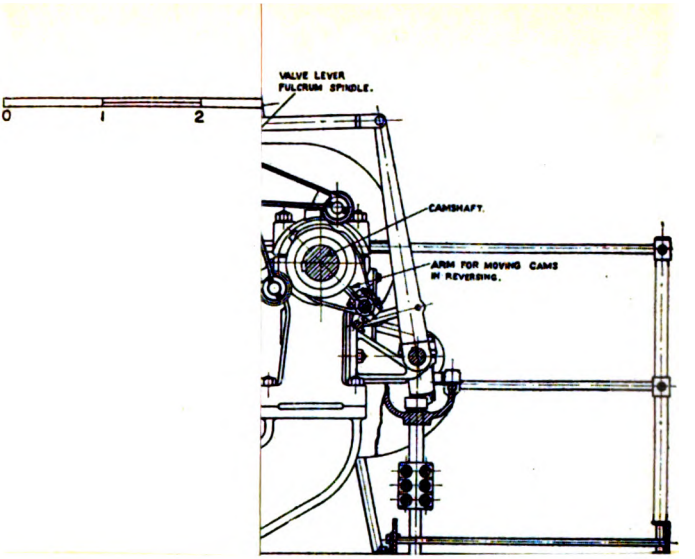

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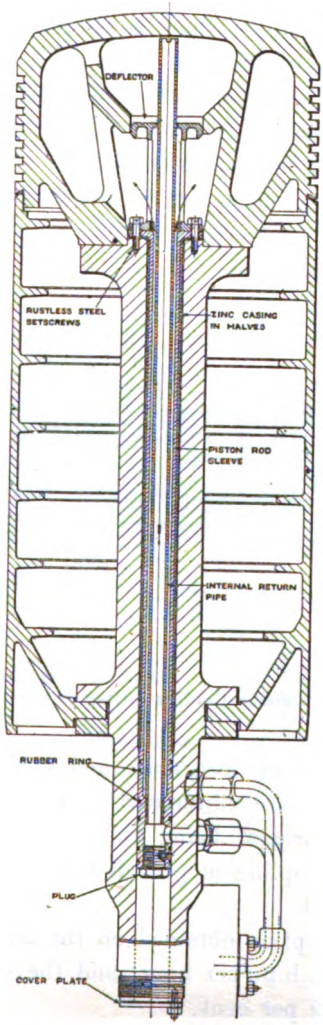

Fig. 38.—Piston of 1,000 b.h.p. Mirrlees-Nobel Engine.

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tricity. The combined effect of this arrangement is to eliminate warping strains.

The top of the cylinder liner is effectively cooled by the arrangement shown in Fig. 40, which is a Nobel patent.

The patented rotary distributor, Fig. 41, driven through gearing from the crankshaft at one-third of the engine speed, controls the suction and delivery of both scavenging pumps. By this means, the noise due to the suction of the air is

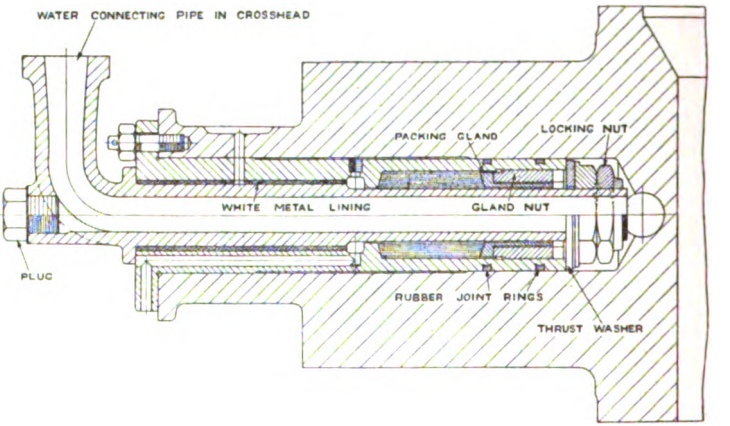

Fig. 39.—Piston-Cooling Fitting in Crosshead.

reduced to a minimum, also noise and wear and tear due to clattering of valves are eliminated. The distributor revolves freely on ball bearings, being thus practically frictionless, while a flexible coupling is provided to allow for any small defect in alignment.

The fuel consumption obtained on the test bed at full load was ·416 lb. per b.h.p. per hour, and the overall mechanical efficiency was 79·2 per cent.

While continuing to manufacture the four-stroke engines they have developed, Mirrlees, Bickerton & Day, Ltd., have adopted the above type as their standard for powers above

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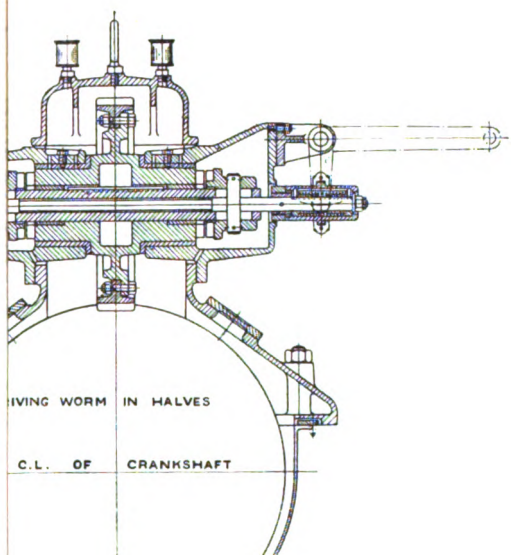

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800 b.h.p., as they are of opinion that for slow-speed high-power engines the two-stroke cycle type has many advantages.

Designs for larger sizes of Nobel engines are in course of preparation, the largest as yet contemplated being a six-cylinder unit of 5,000 b.h.p., to run at 85 r.p.m., which would be suitable for a twin-screw intermediate passenger liner.

This concludes the development of the Nobel engine up to the present time.

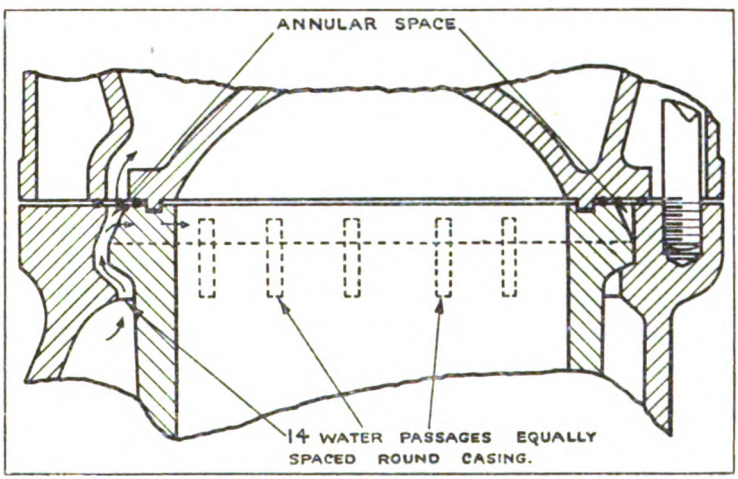

Fig. 40.—Method of Cooling Top of Liner.

Discussion.

Mr. A. J. Campbell (President): I think it will be agreed that Mr. Wilson has succeeded in giving a very comprehensive and a very complete description of the development of the Nobel engine from its early days. It dates as far back as 1897, a good many years before most of us were thinking anything at all about this type of marine engine. I remember during the war that some anxiety existed in America concerning the evolution of a suitable type of aviation engine, and it was resolved that certain designers (I think there were four of them) should be confined strictly in compartments in

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Mr. A. J. Campbell.

a certain hotel in a big American city, and that they should put their heads together, unify their ideas, and produce what would be a satisfactory and highly efficient engine for the purpose. The result of that, it will be remembered, was the Liberty engine, which later proved a very useful and, one might say, accomplished means of driving an aeroplane.

Now, the thought which occurs to me when attending these meetings to hear the different ideas expressed on the Diesel engine is that, surely the time has arrived when a design, combining the principal features selected from the various types of Diesel engine, should be produced. It might be well to isolate designers on the American plan, feed them well, and compel them to a unification of their ideas until they agree upon the best features of the different types, and produce an engine that can be manufactured in various places, so meeting a long felt want. If accomplished, I think a great shipbuilding movement would very rapidly ensue. To-day I mentioned this to a friend who is interested in the Diesel engine, and he said that probably ten years would elapse before any standardisation of general ideas in connection with the internal-combustion engine, such as obtain in the case of the reciprocating engine, took place. While doctors differ patients die, and if engineers do not get together quickly there will be a long period of low pressure in the shipbuilding industry.

I was struck by the reference made, in the early part of the paper, to the Russian cruiser "Rynda," and the feature specially mentioned that great consideration had been given to the use of steel castings with a view to cutting down the heavier weights of cast-iron, cast-iron being reserved only for the cylinder liners. That, I think, was about the year 1910. To-day I understand that a particular firm in America, who have devoted a lot of time and money to the study of cast-steel in order to keep down weight, still retain the cast-iron liner, so that, after all, our American friends are busy to-day with what the Nobel firm were busy with 16 years ago.

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It is a matter of deep regret that a firm such as Nobel's, who have devoted so much time, study, and reserve to the application of this type of engine to all classes of ship, particularly the lighter types for shallow rivers, and to submarines, should be, by the interference of the European war and the action of the Soviet Government, wiped out in the country where they had their birth. I am quite sure it is evidence of the courage and strength of conviction that the Nobels had in connection with the development of the Diesel engine that they unhesitatingly sought another land, and went over to Sweden and started again in 1918, having gathered together their managers, foremen, and some of their men.

Mr. JOHN S. BROWN, M.B.E. (Member): When our President's suggested standardisation of the Diesel engine is eventually carried out, it will call for a close examination of the successive steps through which that engine has been developed; and papers of the type now before us will be most useful in this connection. However, standardisation cannot come until the present pace has slowed somewhat, and the appropriate fields of usefulness have been allocated to the four-stroke and two-stroke cycles in both single- and double-acting forms, to blast-air *versus* mechanical injection of the fuel, to supercharging, and, last but not least, to the range of the power outputs which this engine can provide. The present paper traces the course taken by some of these factors under the skilful guidance of Messrs. Nobel; but it is interesting to notice that the transfer of headquarters from Russia coincides with a very definite deflection from engines with a relatively high operating speed to a more moderate class as required for the propulsion of merchant ships. This reversion does not completely justify the reappearance of the open type engine, as described in the final section of the paper, with its battery of mechanical lubricators, each feeding a measured quantity of oil to a single point. All the other makers of marine engines

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Mr. John S. Brown, M.B.E.
have adopted a system of forced lubrication, which provides each working point with a wide margin beyond the minimum feasible supply of oil, and to this extent allows for contingencies. In these circumstances, it would be of great interest to learn the objects which dictated the adoption of the open engine, and also the lubricating-oil consumption which has been attained on service. In the latter connection, a figure for comparison is provided by the 8·6 gallons per day used in the 1,250 b.h.p. engine for the "Sycamore."*

Another matter on which it would be useful to have further information arises from the reference to reversible marine engines operating on the four-stroke cycle, and with only three cylinders. Here the exhaust and inlet valves open in succession, so leaving only some four-tenths of the cycle during which starting air may be usefully applied. Further, for reversibility, there must always be two such effective cylinders, one in a position for ahead running and the other for astern running. These conditions have led to the present six-cylinder form of the standard four-stroke marine engines, and if Mr. Wilson can tell us how to attain the same ends with only half that number of cylinders we will have had a very profitable evening.

Mr. G. W. Simpson (Student): On page 572, Mr. Wilson gives the weight per b.h.p. of the petrol and paraffin engine and the Diesel engine as 45 to 55 and 90 lbs. respectively. These figures are, of course, fairly old, but where the weight per b.h.p. is very low, due to the use of reciprocating parts made of the lighter alloys, and using the experience gained from the petrol engine, could Diesel engines not be built now which would make the difference in weight per b.h.p. between the two types very small? Unfortunately, petrol and paraffin are still expensive fuels, and it would seem that, from the point of view of the automobile engineer, there is a market for a Diesel engine of low weight per b.h.p.

* Inst. Mechanical Engineers Report, pp. 943-944.

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Mr. A. CAMPBELL (Member): I think Messrs. Nobel deserve great credit for the amount of pioneer work which they have carried out on Diesel engines, and had the Russian revolution not taken place, I believe that Messrs. Nobel would to-day have reaped a greater benefit as the result of that pioneer work. Their licencees, however, are carrying on the good cause, and I can speak from experience of a few visits to the works of Messrs. Mirrlees, Bickerton & Day that their standard of work is excellent, and that the Nobel Diesel engine made by them is reliable. I note that they have reverted to water-cooled pistons in place of oil-cooled pistons, and I should like to know if they found any carbonising of the oil on the crown, and consequent cracking of the pistons in the oil-cooled system.

Mr. S. H. W. DAWSON (Member): Following on Mr. Brown's remarks in connection with scavenging experiments, I should like to say that I have made a great many such experiments, and my experience is that the results are not reliable unless allowance is made for the exhaust gases. This is a rather difficult problem, and some details of the experiments made by Messrs. Nobel would be of great interest. About 1903 Messrs. Hornsby developed a direct reversing hot-bulb engine for pinnace work, and at that time it was considered a great advance on what had previously been accomplished. The engine had complicated gear, but I think it was one of the first reversing engines made.

It appears from the paper that on one or two of the first engines Messrs. Nobel fitted a crosshead, afterwards reverting to the trunk-piston type, which they maintained until recently, when they entered the marine field and produced a 1,000 h.p. engine, changing again to the crosshead type entirely, presumably to meet the wishes of marine engineers, who say they must have a crosshead. It seems that one of the reasons for a crosshead is that engineers have not been able to make the

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Mr. S. H. W. Dawson.
top end pin run in the hot piston on the larger sizes of engine. To me it appears a complication to put a big rotary distributing valve on a scavenging pump when ordinary small automatic valves will do the work. Is any advantage to be gained by quick opening with a mechanically-opened valve?

Mr. R. J. Butler (Member): As in the important series of papers on Diesel engines which have been presented to the Institution the relative weights of various designs of about the same power have been quoted, it would be of value if the weight for the 1,000 b.h.p. Mirrlees-Nobel marine engine could be added for comparison. The rather complicated mass of gear, shown in the sectional view, Fig. 37, of the paper, appears to indicate that the weight is of the same order as that of a four-stroke engine of equal power and revolutions per minute. The fuel consumption is given as ·416, which, whilst good for a two-stroke engine, can be considerably bettered in a four-stroke design.

It would also be interesting if the lubricating oil consumption could be given of the engine which has lately gone through its trials at Stockport, at which very few of us had the privilege of attending. It is not to be expected, of course, that this figure can be within measurable distance of that obtainable with four-stroke engines, but as I am personally interested in these characteristics I should be glad if Mr. Wilson could see his way to give these particulars.

Mr. F. L. MacLaren (Member): Nineteen years ago I completed my training under Prof. Watkinson, and decided to take up the propulsion of boats by internal-combustion engines. I built two which ran on producer gas, and spent a considerable sum of money in the process, but under the influence of the late Mr. May I ceased work in that direction on the report that Messrs. Nobel were making very rapid progress in Russia with the propulsion of boats by oil engines.

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Mr. F. L. Ma Laren.

Although a Scotsman, I was born in Petrograd, and it has been a great pleasure to me to listen this evening to such a concise and complete description of Nobel's activities in Russia, and I thought it would be doing an injustice to Mr. Wilson if I did not just mention how my appreciation of the work that Messrs. Nobel carried out in my native country affected my life's work, which is the building of motor boats.

Mr. GEORGE R. GRANGE, B.Sc. (Associate Member): I recently had the privilege of witnessing Messrs. Mirrlees, Bickerton & Day's 1,000 h.p. Nobel engine running at Stockport, and was much impressed by the quietness of the engine, especially the scavenging pump with its rotary valve. There are two questions which I wish to ask Mr. Wilson about the engine. Firstly, the two-stroke engine has the reputation, rightly or wrongly, of having a high lubricating-oil consumption, and it will be very interesting to learn how the open two-stroke engine compares in this respect with the enclosed engine. The fact that the piston skirt does not descend at each stroke into the oil mist of an enclosed crankcase should materially reduce the oil consumption. Secondly, what is the reason for the bevel angle on the outside of the cylinder liner at the point where it joins the cylinder jacket? I do not understand whether this bevel is made in order that the hoop stress in the liner may be transferred to the jacket, or whether it is due to an attempt to reduce the stress existing in the liner top itself, caused by variations in temperature and by the tension of the cylinder cover studs.

Mr. W. W. MARRINER (Member of Council): From a perusal of the paper, it would almost appear that what the President proposes has already been done, and that some of the best brains in the Diesel engine field have come together and produced an engine in which shipowners ought to have every confidence.

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Mr. W. W. Marriner.

With a view to using Diesel engines in high-speed and shallow-draught vessels, it was my good fortune, in 1897, to visit the various firms in Augsberg and Munich who were making these engines, and to see at that time the original Diesel engine, a Diesel engine for pumping water in an hotel, one for driving the machinery in a flour mill, and another for producing electricity in a locomotive works. From there a visit was paid to Bar-le-Duc, in France, where the first marine engine referred to by Mr. Wilson was on view. It was a reversing engine with four camshafts. Looking for an engine which would be light, I was told by the builders that they hoped to get one horse-power per 100 lbs. weight, but when the engine was built the weight was 200 lbs. per horse-power. In the case of some of the early engines referred to in the paper, 60 lbs. per horse-power is mentioned, and in the latest engine the weight is given as 300 lbs. per horse-power. It is a pity that this weight question cannot be overcome, because it prevents the extensive use of heavy oil engines.

One of the very early Hornsby engines, referred to by Mr. Dawson, was put into a second-class torpedo boat by Messrs. Yarrow & Co., who were building a good many of these boats at the time. The result with this engine, which was a most beautifully made machine and worked extremely well, was a speed of 14 knots, while with the same weight of steam machinery a speed of 20 knots was obtained. I do not think that even to-day a much better comparative result can be obtained.

Mr. P. A. McKillop (Member): Referring to the early history of the Diesel engine, may I mention that in the Glasgow Exhibition of 1901 there was a small horizontal Diesel engine driving a dynamo, and as far as I remember the fuel consumption was stated to be ·5 or ·6 lb. per horse-power hour. The question of the consumption of heavy lubricating oil has been raised by other speakers. I have had considerable experience of the lubrication of many types of engines, and think the

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high consumption of lubricating oil takes place in engines where the trunk piston enters the crank-chamber. The circulating of the oil causes an oil mist, which gets sucked up into the cylinders.

Mr. C. R. H. Bonn (Associate Member): The patents for the Diesel engine have run out; the only things connected with it which may be patented to-day are the different attachments, such as gears, pumps, compressors, etc. It would, therefore, be interesting to know the real reason why some British Diesel engine builders manufacture foreign types. It is indeed questionable whether all the various arrangements are warranted, and there appears to be a strong justification for the President's plea that British manufacturers should get together and pool their ideas after the manner of the designers of the American aeronautical engine. An engine for marine purposes might then be produced which would be at once simple, reliable, efficient, and durable. Such an engine could be standardised, and, consequently, would be cheap to build, while replacements could be stocked at ports of call, the world over, ready for any emergency.

I was pleased to learn the other day from a superintendent engineer at a foreign port who undertakes the repair of Diesel engines, that the best engine, in his opinion, with respect to reliability and durability, is one of entirely British conception built on the North-East Coast.

Mr. T. H. Matthews, M.A.: Figs. 38 and 39 show details of the piston cooling arrangements, and I should like to ask if any trouble has been experienced with this arrangement of cooling by means of swinging links. Some years ago I was associated with a firm that built a Diesel engine with similar cooling arrangements, and there was a certain amount of trouble and expense in keeping the joints tight, and the wear infinitesimal when running at high revolutions. Satisfactory

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arrangements at low costs are still needed for the piston cooling of Diesel engines. Many superintendent engineers have different views on the subject; some prefer oil, others salt or fresh water.

At the present moment a two-stroke port scavenging engine is being opened up, after having been constantly in use for over four years at sea, the ship having run approximately 260,000 miles; and where salt deposit was expected, namely, on the jackets, liners, piston heads, and in the cylinder covers, very little was found, scarcely $\frac{1}{32}$ inch on the piston crown and less on the jackets and liners, showing that the quantity of water in circulation is not too small to allow of an increase in temperature sufficient to deposit salt, and when an ample supply of salt cooling-water is arranged no deposit worth mentioning is found from experience with the Sulzer type of engine.

From examination of the jackets and liners of the above-mentioned engine, it would appear advisable to consider two circulating water inlets to the jacket at the bottom, in place of the general practice of one in way of the exhaust-port water-cooled bars. The cooling water, where there is only one inlet, appears to take the easier course of efficiently cooling the exhaust-port bars and starving the scavenging-port bars directly opposite. The exhaust-port bars were found to be in excellent condition, but the scavenging-port bars were in many cases choked with silt and sand, having received no attention for cleaning during the four years in service. It would also appear necessary always to arrange for a high and low suction where salt-water cooling is used; the high suction to be used in rivers, or shallow sandy waters, and even perhaps the addition of some form of sponge filter box to trap any sand or silt that may pass through the usual perforated plate type of strainer fitted.

Fresh water or oil cooling is of interest, but costly, and where cost is of first importance salt water, if used efficiently, need cause no anxiety.

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Mr. G. E. E. Burgess.

Mr. G. E. E. Burgess: Mr. Wilson deserves the thanks of all connected with the construction of oil engines for giving so many details of the large number of engines constructed by the Nobel Co. for service on the rivers and inland seas of Russia. The results obtained with the large fleet of vessels engined by Nobel are almost unknown to the outside world, and on a future occasion perhaps Mr. Wilson will be able to give still further information on this subject.

The amount of information available is illustrated by the fact that Mr. Wilson mentions instances of engines direct coupled to rolling mills, examples of the Del Proposto system of drive, geared drive with friction and electro-magnetic clutches, Diesel-electric drive, and ordinary direct-coupled reversible engines, some of which are still in use after 22 years' service. Perhaps the most extraordinary engines mentioned in the paper are those of the "Imperatritza Alexandra," in which the bearings are lubricated with large quantities of oil, subsequently burned under the donkey boiler. Further particulars of the class of oil, quantity used, and the results to the engine would be interesting, as the use of oil, which no doubt had volatile constituents, in the crankcase of an internal-combustion engine appears to be a doubtful expedient.

The other interesting feature of this engine is the arrangement which allows it to run either on the two- or four-stroke cycle, and although this was not absolutely necessary in this particular engine, there are, perhaps, cases where it might still be of use. For instance, in the case of auxiliary engines on board ship the system appears to be worth consideration, as by its adoption the auxiliary engines might operate on the four-cycle system during the long periods at sea, the load then being generally comparatively light, and on the two-cycle system during the short periods of heavy load when all the winches are in operation in port. The engines would then be somewhat lighter and cheaper than if full-powered four-cycle sets were installed, and the durability would not be much

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Mr. G. E. E. Burgess.
affected, as the periods under heavily loaded two-cycle operation would be short.

Referring to the scavenging of the Mirrlees-Nobel engine, Mr. Wilson gives two light spring diagrams taken with mechanically-operated and automatic-scavenging admission valves, and suggests that the higher pressure in the cylinder, when the scavenging ports close with the latter type of valve, is due to their action as non-return valves preventing the return of the air to the scavenging air space as the piston moves upward. Is it not true, however, that with the scavenging and exhaust ports of the same height as in the Mirrlees-Nobel engine, the air would be discharged to the exhaust if prevented from re-entering the scavenging system? From the diagrams given, it would appear that the delay in opening the automatic valves, due to the back pressure in the cylinder, is beneficial in this respect, as the scavenging air supply in the pipes and passages adjacent to the cylinder is not unnecessarily depleted before the main piston commences the up stroke, and thus the stroke commences with a pressure of scavenging air in the cylinder of ·14 atmosphere with the automatic valves, whereas the pressure is only about ·045 atmosphere with the mechanically-operated valve.

It is very satisfactory to have the assurance that the simpler arrangement is the best supported by such definite practical results, and to find that the automatic-valve arrangement has been definitely adopted by Messrs. Mirrlees, Bickerton & Day.

Mr. Lewis A. Smart (Member): In 1903, as consulting engineer for the Leeds and Liverpool Canal Co., I designed a variable speed Diesel engine equipment for a cargo-carrying tug which was constructed early in 1904, and, after considerable service, was dismantled because the Mersey Dock and Harbour Board would not allow it to navigate their waters, where craft carrying oil were prohibited. The dimensions of this boat were as follows:—Length, 61 feet; beam, 13 feet

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9 inches; and draught, 3 feet 10 inches forward and aft when loaded with 30 tons of cargo and 14 cwts. of fuel. The engine installed was a two-cylinder, single-acting, four-stroke cycle motor of the ordinary land type, with cylinders 210 mm. in diameter by 340 mm. stroke, and a normal speed of 240 r.p.m., developing about 35 b.h.p.

Before dismantling the engine in 1906, I subjected the tug to a series of progressive trials, quarter loaded, half loaded, and fully loaded, with and without one or two barges in tow. Thereafter the engine was used ashore, and a steam engine was fitted in the tug to the Mersey Dock and Harbour Board's requirements. The fully loaded test showed that, with fuel oil at 40s. per ton, the cost was less than $\frac{1}{100}$th of a penny per ton per mile when travelling at an average speed of 3·28 miles per hour under fair canal conditions as to depth of water, etc., and experience, under working conditions, confirmed this figure. The speed was slightly greater than that of the steam-driven barges, and, though slow, was the maximum permissible on the canal, which had a hydraulic section of only about 190 square feet. At the half loaded test the cost for fuel oil per ton-mile was ·014 of a penny, while when the barges contained only a 25 per cent. load, the cost had risen to ·026 of a penny. The fuel oil per b.h.p. per hour was ·42 lb., ·45 lb., and ·48 lb. respectively for full, half, and quarter loads carried by the boats, and it is interesting to note that the horse-power of the engine remained practically constant. Perhaps one of the most interesting features brought to light was the hitherto unsuspected capacity of the Diesel engine to run efficiently at widely varying speeds, the engine in question having proved itself capable of working at any speed from 60 to 270 r.p.m.

Mr. Wilson gives credit to Russia and France for alone pioneering this development, but I think the Institution should establish a claim for Britain to rank alongside, if not ahead, of them. The makers of my engine certainly believed that we were

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Mr. Lewis A. Smart.

the first. Speaking from memory—and Mr. Wilson's paper seems to confirm my recollection—the first French marine Diesel engine was of the two-stroke cycle type, and I think so also was the Russian. Mine was four-stroke cycle. What I claimed credit for was proving to the constructors that the engine would (and did) maintain its efficiency through considerable variations in speed. This I did, first by calculations, and thereafter by a series of tests on what, at that time (1902), were the two largest Diesel engines then running in Great Britain.

I have extracted much of the foregoing from Mr. A. P. Chalkley's book on "Diesel Engines" (1912), the introduction to which was written by Dr. Diesel.

Mr. Wilson: From the point of view of minimising the cost of production, I agree with Mr. Campbell's remarks on the question of standardisation, but standardisation on the scale indicated would undoubtedly tend to retard the development of a type of prime mover which, like the Diesel engine for larger marine work, is still in its infancy. Further, there is no doubt that Mr. Brown's remarks on this question later in the discussion sum up the position at the present time.

Difficulty is sometimes found in making reduction of weight and low production cost compatible, and this no doubt retards the more extensive use of steel castings as well as other special materials. If, however, lightness is essential, much can be done in this direction in the manner indicated in the paper.

I would remind Mr. Brown that Messrs. Nobel were building slow-speed engines previous to the Russian revolution. Further, they found that the many large submarine engines which they had built ran satisfactorily without forced lubrication, and as they were desirous of producing an engine which would appeal to marine engineers by its simplicity and accessibility they decided to construct an open-type engine without forced lubrication.

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The method adopted by Messrs. Nobel in the three-cylinder reversible four-stroke Diesel engines was an arrangement whereby the starting-air valve and the exhaust valve could be operated on the two-stroke cycle, and the air and fuel valves could be put out of action during manœuvring operations. Similar methods have been adopted by other manufacturers to overcome the difficulty suggested by Mr. Brown.

In reply to Mr. Simpson, I may state that as early as 1909 Messrs. Nobel considered the application of the Diesel engine for motor car propulsion, and built a 12 b.h.p. single-cylinder experimental engine with a speed of 1,300 r.p.m. The main object of the tests on this engine was to ascertain the highest speed a fuel pump would operate at while properly supplying fuel to the cylinder. On page 572, it will be seen that Messrs. Nobel produced a Diesel engine with a total weight of 22 lbs. per b.h.p. Several Continental manufacturers have built Diesel engines with a weight of 22 lbs. per b.h.p. for commercial motor vehicles and motor ploughs, and have demonstrated their reliability.

With regard to Mr. A. Campbell's question on the cooling of pistons, my own firm, Messrs. Mirrlees, Bickerton & Day, Ltd., have always preferred to cool pistons with water, as it has been felt there is always a danger, when using lubricating oil, of the oil being carbonised on the upper portion of the piston, particularly so if the oil is not circulated through the piston after the engine has been shut down. If carbon does form on the upper portions of the piston, then it acts as an insulator, and produces overheating and ultimate cracking of the pistons. Furthermore, great care has to be exercised in the quality of oil that is passed through the pistons, while complicated cooling devices have also to be fitted. It is to be understood, however, that they do not regard oil cooling as an entirely unsatisfactory arrangement, as it is quite possible, with carefully devised arrangements, to use it with satisfactory results. They have carried out investigations and experiments

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Mr. P. H. Dixon Wilson.
with regard to the use of high conductivity materials for pistons, such as copper-aluminium alloys, and have a large number of engines running with this type of piston, of about 12 inches diameter. They have also made larger sizes of 17¼ inches diameter, and the results have been quite good, but the high cost of such pistons and the difficulty in obtaining sound castings have precluded them from adopting the larger sizes generally.

I agree with Mr. Dawson's remarks on scavenging experiments. Messrs. Nobel used a special full-sized glass cylinder, and through suitably designed gear it could be filled with exhaust gases. To facilitate the observation of the streams of air entering the cylinder, the scavenging air was coloured. Besides visual tests, gas analysis tests were made during these experiments. My firm have carried out a large number of scavenging experiments, and found that the arrangement of exhaust piping and silencers made material differences. Experience showed that the exhaust pipes must be of large diameter, and there must be as few bends as possible.

With reference to Messrs. Hornsby's direct-reversing hot-bulb engine, at the same time that this was made Messrs. Mirrlees, Bickerton & Day also built three Diesel engines for pinnace work, and the results were very satisfactory indeed. These were said to be a great improvement on any other internal-combustion propelled vessel which had been built up to that time.

With regard to the question of crossheads, the first Diesel engine made in this country, in 1897, was also fitted with a crosshead, but, owing to the cost of manufacture and the material successes that had been obtained with the trunk piston on gas engines built at that time, the designs were changed to the trunk-piston type, of which there are thousands at work giving satisfactory results, even with uncooled pistons of 20 inches diameter. Great care has to be taken in the method of lubricating the piston pin. In the last five years

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Mr. P. H. Dixon Wilson.

my firm have developed a floating piston pin with reinforced bearings both in the rod and piston. The advantage of this type is that the pin rotates and assists the lubrication by doing so, and at the same time produces uniform wear on the pin. Should the bearing get hot, the pin is also free to expand without causing any distortion to the piston. It will be realised that another advantage is that the pin can be readily removed and replaced by hand without having to resort to any mechanical device, which invariably distorts the piston.

Regarding the rotary distributing valve for the scavenging pump, at first glance this would appear to be complicated, but as a matter of fact it is an exceedingly simple arrangement, as it enables predetermined admission and delivery periods to be fixed. There is an elimination of valves and springs which are liable to give trouble, and it was considered more important to have something that was positively driven, reliable, and which would not cause any anxiety to the operating engineers.

In dealing with the question of lubricating oil consumption raised by Mr. Butler, I may say that figures have been taken from time to time, and an average of these shows that the quantity of lubricating oil used was 4 lbs. per engine hour. This, no doubt, could be reduced if the engine was enclosed, as on enclosed engines capable of developing 600 b.h.p. continuously, and running at 250 r.p.m., the lubricating oil consumption has been as low as 2·9 lbs. per engine hour. This latter figure was taken over a period of 3 to 4 months' running under actual load conditions in the power station. The weight of the Mirrlees-Nobel marine engine is 9·5 tons per 100 b.h.p.

I wish to thank Mr. MacLaren for his remarks regarding Messrs. Nobel's activities in Russia.

I have dealt with Mr. Grange's question on the subject of lubricating oil in my reply to Mr. Butler, but I may add that the bad reputation of the two-stroke engine in respect to this particular point has been produced from the unfortunate experience of those using the crank-chamber compression type

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Mr. P. H. Dixon Wilson.
where the quantity of lubricating oil is uncontrolled, passing as it does from the crank-chamber in a mist with the scavenging air. Furthermore, I am of the opinion that the cylinder lubrication of the ordinary two-stroke engine is usually very high, but in the Nobel engine mechanical sight-feed lubricators have been fitted, the feed being controlled and visible, and at the same time delivered at six different points, each point being fed by a separate lubricator. This arrangement materially reduces the lubricating consumption, as it is possible to deliver the exact quantity to the point where it will give the best results.

The bevel angle shown on the outside of the cylinder liner at the point where it joins the jacket centralises the liner in the jacket without its being bound diametrically. Also there is no sudden change of section, and the angle materially assists the flow of the water into the ports and prevents any tendency to air locking.

I may remind Mr. Marriner that the weight per horse-power of a Diesel engine depends on the speed, and the light engines referred to in the paper are of a high-speed type to be used for naval vessels or light river craft. The latest engine is of the slow-speed type designed for cargo vessels of the mercantile marine. Personally, I do not think the weight question prevents the extensive use of the Diesel engine, and would refer Mr. Marriner to my remarks in replying to Mr. Campbell.

The engine referred to by Mr. McKillop was a small horizontal two-stroke engine built by a well-known firm of Lancashire engine builders. The fuel consumption was comparatively high, and I believe that mechanical difficulties were experienced with the scavenging arrangements.

There is no doubt that the lubricating oil consumption of many engines of the enclosed type is exceedingly high. Care has to be taken in design to prevent the piston being exposed unduly to the oil mist which is present in the crankcase, but there is another point which causes high lubricating-oil con-

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sumption, namely, the leakage of oil which passes down from the piston pin in cases where it is lubricated under pressure. This surplus oil runs down the inside of the skirt of the piston and covers the liner with a heavy film of oil when in its upper position, and unless adequate means are provided to rid the surface of the liner of this abundance of oil, it is driven up past the piston rings by hydraulic pressure, and ultimately finds its way into the combustion space and is burned. Very often such engines have a low fuel consumption, the reason being obvious.

I have dealt with the question of standardisation earlier in my reply, but would refer Mr. Bonn to Mr. Marriner's opening remarks. It is undoubtedly less costly to take up a licence for a Diesel engine which has already been fully developed and proved thoroughly reliable than to design a new type and bear the cost of the consequent experimental work which must be undertaken.

Mr. Matthews raises the question of trouble with the piston-cooling system when using the swinging link arrangement, but very little trouble has been experienced with the design adopted by Messrs. Nobel. There was, in the first instance, minor trouble with the flexible tube between the supply pipe and the swinging link, but this has now been rectified, and during a recent visit to the "Zoroaster" I was informed that the flexible tubes in use had been working for 15 months, and that the whole system was now entirely satisfactory. The Mirrlees-Nobel engine has two water-circulating inlets to the jacket at the bottom, with cooled bars in the liner for both scavenging and exhaust ports. The trouble referred to by Mr. Matthews has not been experienced. It is quite a common practice to adopt high and low suctions for circulating water in such vessels as oil tankers and others having to navigate rivers or sandy waters, and I recommend this method to be used in all such cases.

I thank Mr. Burgess for his very interesting contribution to

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Mr. P. H. Dixon Wilson.
the discussion. The lubrication of the crankshaft bearings of the engines in the "Imperatritza Alexandra" was with Nobel's mazout (boiler fuel oil). Specific gravity, ·909/·915; flash point, 100° – 109° Pensky; and viscosity at 50 degrees C., 5 degrees Engler. Concerning the question of automatic and mechanical scavenging control, I may point out that with both systems the time when the scavenging air enters the cylinder is dependent on the pressure in the cylinder. It would at first appear that with the exhaust and scavenging ports at the same height there should be no rise in pressure in the cylinder until the piston covers the ports, but due to the special design of the scavenging and exhaust ports, and the piston crowns, this rise of pressure takes place as shown by the diagrams, and I can assure Mr. Burgess that the reason given in the paper is correct.

Mr. Smart suggests that I have given all the credit to Russia and France for pioneering work in connection with the development of the Diesel engine, but I hardly think this is correct, as I would not be doing justice to my own firm, Messrs. Mirrlees, Bickerton & Day, Ltd., who were the pioneers in this country. All I have attempted is to show the very extensive experience Messrs. L. Nobel, Ltd., have had in this field of engineering, more especially as it is not generally appreciated that so much pioneer work was done in Russia.

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THE BRACKETLESS SYSTEM.

By Sir JOSEPH W. ISHERWOOD, Bt., and WILLIAM ISHERWOOD.

23rd March, 1926.

THE introduction of the "Isherwood" system of ship construction in the year 1907 has been followed by most gratifying results, and has been an unqualified success. The total number of vessels of all types built and now being built is 1,502, having an aggregate carrying capacity of 12¾ million tons. Of this number 705, of 6¾ million tons deadweight carrying capacity, are oil tankers, and comprise the bulk of the world's tonnage for this class of vessel.

The Isherwood system is so well known that a description of it is unnecessary. Apart from its success, the highest possible compliment that could be paid to it is the fact that Lloyd's Register of Shipping has adopted the system in the formulation of its rules for oil-carrying vessels, and it now becomes the standard of strength for vessels engaged in the exacting conditions obtaining when carrying oil in bulk.

Experience with the transverse construction for oil tankers is not so old as to be forgotten by those whose business it is to operate this class of vessel. In the old style transverse method of construction (now obsolete) there was continual trouble and leakage in the bracket connections at the oil-tight bulkheads, and this in addition to the various damages sustained in bad weather, due to the deficiency in longitudinal stiffening and general longitudinal strength. The Isherwood system overcame the latter trouble, and very greatly minimised the former.

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Mr. J. Foster King, the principal surveyor of the British Corporation for the Survey and Registry of Shipping, when discussing a paper read by Mr. Isherwood (now Sir Joseph Isherwood) in 1908 before the Institution of Naval Architects, stated:—

"The value of Mr. Isherwood's departure in construction will not be limited to the utilisation of fore and aft distributing members, but will have the effect of bringing new thoughts to bear upon accepted methods of shipbuilding. If this new design shows that the whole of the transverse attachments, beam-knees, margin attachments, etc., to which we are accustomed, can be satisfactorily localised at intervals of 12 feet, then modifications of opinion as to many details must result, and further steps will be made in the direction of simplicity. . . . Nothing on earth is free from sins of omission or commission, but there is every reasonable expectation that this ship will be a structural success, and whatever faults she may have, there can, I think, be no doubt as to the valuable technical qualities of the design."

Time and events have proved that Mr. King was speaking with the tongue of a true prophet, as not only have his expectations been realised in regard to the structural success of the design, but the introduction of the Isherwood system has brought new thoughts to bear upon the accepted methods of shipbuilding practised at that time, and inessential parts which were then considered to be of great importance have since been omitted from transversely-framed vessels. During the period of 1908-1925, however, the Isherwood construction has only been modified in detail, and that to a very small extent.

The purpose of this paper is to bring to the notice of this Institution a great departure in the system of oil-ship construction. The practical reasons for this, and the technical explanations in support of the departure will be given.

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In the development of the Isherwood system for oil tankers, it was considered essential to connect all the longitudinals to the transverse bulkheads, not only those on the sides and bottom and deck of the vessel, but those also on the middle-line bulkhead, and at the same time to connect the horizontal stiffeners on the transverse bulkheads to the longitudinals on the shell of the ship and those on the middle-line bulkhead, this being accomplished by the use of brackets.

Whilst greatly minimising, if not entirely overcoming, the trouble experienced at the bulkhead connections in transversely-framed vessels due to heavy weather, was only attained at considerable cost and some inconvenience in the building operations. Further, when damage is sustained in the vicinity of the bulkhead brackets in a tanker, due to grounding or other causes, the cost of repairs can easily be understood to be great. Hence the reason for the "Bracketless System" which we have in collaboration developed.

Whilst this system is applicable to all types of vessel, whether longitudinally framed or transversely framed, we propose to confine our attention particularly in this paper to vessels designed for the carriage of petroleum or other liquids in bulk, and stiffened in the longitudinal direction, or, in other words, we propose to deal with a design of an oil-tank vessel on the pure Isherwood system, with the exception that all the brackets usually fitted for the purpose of connecting the longitudinals to the bulkheads are entirely eliminated, *i.e.*, there are no corner brackets whatever throughout the oil tanks.

Having satisfied ourselves that the continuity of strength could be maintained with the brackets eliminated, the first consideration in the design of the bracketless tanker was the spacing and strength of the transverses. It is obvious that the transverses have more work to perform when the brackets are omitted, as that part of the work performed by the bulkheads in fixing the ends of the longitudinals is now transferred to the deep transverses, and these, of course, require to be of

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increased strength as compared with corresponding transverses in the bracketed design.

Making the comparisons, therefore, with the tanks the same length in both the case of a bracketless ship and a bracketed ship, it was necessary to determine the spacing of the transverses, which, of course, must be in some definite relationship to the strength of the longitudinals. This was not an easy matter, and we called to our aid Clapeyron's Theorem of Three Moments. This theorem has not to our knowledge been put to any practical use in shipbuilding investigations. It is well known, however, to structural engineers, and is the theoretical consideration of a continuous beam supported at three or more points.

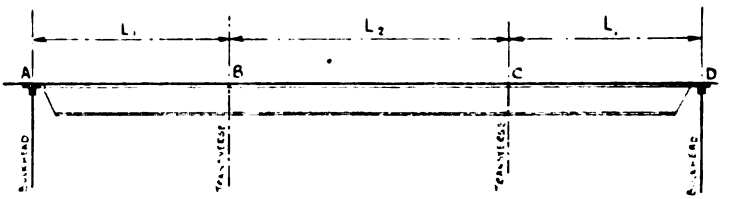

Fig. 1.

In other words, the longitudinals are treated as continuous beams between the transverse bulkheads, the transverses in the tank—two or more, two in the case under consideration—and the two bulkheads being considered as supports to the longitudinals, as shown in Fig. 1.

In view, however, of the deep transverses being strongly attached to the shell plating, and the longitudinals which pass through the transverses being also strongly riveted to the shell plating, the point of intersection of the longitudinal with the transverse can be regarded as a point of comparative fixity, rather than a point of support, and especially so as the longitudinals are lugged and substantially attached to the transverse. Although for all practical purposes the point of intersection has been regarded in the past as one of fixity, the

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assumption that the transverses are only points of support is on the safe side, and provides an additional margin of safety to that shown by the results of our investigations.

In a vessel of 10,800 tons deadweight carrying capacity now being constructed at the Jarrow yard of Messrs. Palmers Shipbuilding & Iron Co., Ltd., the ratio of spacing of transverses adopted in tanks 28 feet 3 inches long is 7—10—7, namely,

8 feet 3 inches from bulkhead to adjacent transverse,
11 ,, 9 ,, ,, transverse to transverse,
8 ,, 3 ,, ,, ,, ,, bulkhead,

and the same ratio is adopted for the example now given but for tanks 29 feet long. In the case under consideration, bottom longitudinals of 17-inch channels are used.

As some hundreds of ships have been built which have satisfied us that there can be no doubt about the strength of the longitudinal at the middle span, which is in an almost analogous condition in both systems, it is, therefore, safe, with the further aid of the diagrams about to be described, to make our comparison of strength on this span.

In order to arrive at a suitable spacing of transverses and to know the conditions at any point on the longitudinals, we considered it necessary to construct diagrams showing the free bending-moments, fixed bending-moments, shearing forces, and deflections for varying spacing of transverses, in order to determine the proportion of the load to be taken by the spans between the bulkheads and adjacent transverses as compared with the load taken by the spans between the transverses, with the latter of which, it might be assumed, we are fairly conversant, in view of the experience gained from the ordinary Isherwood system. The ratios taken are 10—10—10; 9—10—9; 8—10—8; and 7—10—7.

The shearing stresses, bending-moments, and deflections have been calculated on the assumption that the beam extend-

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ing continuously from A to D is supported unyieldingly at the points A, B, C, and D, the distances AB and CD being equal, and the beam uniformly loaded throughout its length.

Although it must be obvious that there must be a certain amount of fixity or moment of constraint at the points A and D, the beam has been assumed to be simply supported at these points, and it can be shown, by an adaptation of Clapeyron's Theorem of Three Moments, that if M_A, M_B, M_C, and M_D be the fixed bending-moments of A, B, C, and D respectively, w the uniform load on unit length of beam, and l_1 and l_2 the length of the different spans,

$$M_A l_1 + 2M_B(l_1 + l_2) + M_C l_2 - \frac{w}{4}(l_1^3 + l_2^3) = 0 \quad \text{(a)}$$

and

$$M_B l_2 + 2M_C(l_2 + l_1) + M_D l_1 - \frac{w}{4}(l_2^3 + l_1^3) = 0 \quad \text{(b)}$$

but M_A and $M_D = 0$ as the ends of the beam are free, and by symmetry $M_B = M_C$.

$$\text{From (a)} \quad M_B(2l_1 + 2l_2 + l_2) = \frac{w}{4}(l_1^3 + l_2^3)$$

$$\therefore \quad M_B = \frac{w}{4} \times \frac{(l_1^3 + l_2^3)}{(2l_1 + 3l_2)}.$$ This is the general formula (c) which has been used for calculating the bending-moments on the longitudinals at the point of support given by the side transverses. These are the maximum bending-moments on the longitudinals as shown by the diagrams.

It is interesting to note the difference in the bending-moments and deflections for the varying spacings of 10—10—10; 9—10—9; 8—10—8; and 7—10—7.

The procedure adopted in preparing these diagrams is as follows:—

1. Bending-moment curves are drawn on each span for a beam having free ends, the maximum ordinate of which is equal to $\frac{wl^2}{8}$ at the middle of each span.

2. The moment of constraint in way of the two transverse

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supports is calculated from formula (c) and marked on the diagram. Straight lines are then drawn joining these two points and zero points at the ends of the beam. This line is drawn on the same side of the base line as the free bending-moment curve, and to the same scale. The distance between the free bending-moment curve and the straight lines representing the moment of constraint at any part of the beam or longitudinal, gives the actual bending-moment at the part.

It will be seen from the diagrams that it has a maximum value at the points of support given by the two side transverses.

It is interesting to note that whilst the bending-moment at this point reaches the greatest magnitude, it diminishes very rapidly to zero on leaving the point of support; the distance from zero point on one side of the transverse to zero point on the other side is a comparatively small proportion of the length of the beam, whereas the bending-moments at the middle of the spans, whilst much less severe, are sustained over a greater length of the beam.

3. The lines representing the shearing forces on the beam are now drawn.

Contrary to the usual procedure, the shearing-force diagram is derived from information obtained from the bending-moment diagram in the following manner:—

$$\text{Support at D} \times l_1 = \frac{wl_1^2}{2} - \text{moment of constraint at C.}$$

$$\therefore \text{ Support at D} = \frac{\frac{wl_1^2}{2} - \text{moment of constraint at C}}{l_1}$$

Taking moments about B,

$$\text{Support at C} \times l_2 + \text{support at D} \times (l_1 + l_2) = w\frac{(l_1 + l_2)^2}{2} - \text{moment of constraint at C.}$$

$$\therefore \text{ Support at C} = \left(w\frac{(l_1 + l_2)^2}{2} - \text{moment of constraint at C} - \text{support at D} \times (l_1 + l_2) \right) \div l_2.$$

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Shearing force at D is then marked on the diagram, and the total shearing force at C is divided so that one part equals the shearing force at $D - wl_1$. This value is marked off on the line through the point C on the opposite side of the base line. The two points C and D are then joined, and the distance between this line and the base line at any part of the longitudinal from transverse to bulkhead represents the shearing force at that part.

The remainder of the shearing force at C equal to $C - (D - wl_1)$ is then marked off on the opposite side of the base line, and the point so obtained is joined by a straight line to a point on the line through B, so that this line intersects the base line at the mid-length of the middle span. This line represents at any point the amount of shearing force on the middle span at that point. The line representing shearing forces on the span A to B can then be drawn in a similar manner to that given for the span C to D, taking care to set off the value of shearing force at A on the opposite side of the line to that at D.

Here again it will be noticed from the diagram that the shearing forces are greatest in way of the two transverses, thus necessitating a close spacing of the rivets attaching the longitudinal to the shell plating at this part, Diagram E.

From the shearing-force diagrams and also the bending-moment diagrams, it will be seen that, by reducing the end spans and increasing the middle spans, more work is thrown on the transverse and longitudinal in the vicinity of the transverse, but the stresses on the longitudinals in way of the bulkhead are considerably reduced.

4. As the amount of deflection on the structural parts is one of the principal factors affecting the oiltightness of a tanker, it is necessary to give it careful consideration. With this in view, deflection curves have been drawn on the four diagrams A, B, C, and D for bottom longitudinals, to find out the effect of the various ratios of spacing of transverses.

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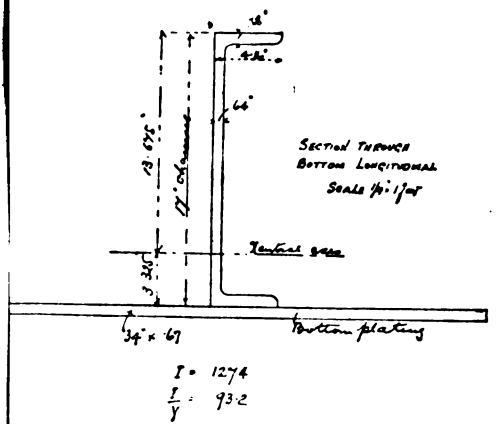

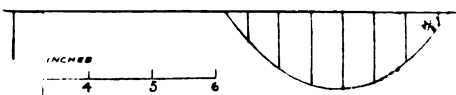

verses). **Span Ratios 9-10-9.**

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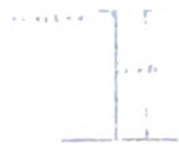

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These curves have been obtained graphically by first drawing a curve of $\frac{M}{EI}$ where M equals the bending-moment in inch-tons, and E the modulus of elasticity of riveted steel-work, which in these calculations has been taken at 10,000. and I is the moment of inertia of the cross-section of the longitudinal, including shell plating.

The curve is then integrated twice, giving the curves

$$\int \frac{M}{EI} . dx \text{ and } \int\int \frac{M}{EI} . dx . dx.$$

The terminals of the second curve are then joined by a straight line, and the vertical distance between this straight line and the second integral curve at any part represents the deflection in inches at that part.

The following tables show the variation in maximum bending-moments, shearing forces at the ends of the longitudinals, and maximum deflections on the spans adjacent to the bulkhead:—

TABLE I.

MAXIMUM BENDING-MOMENTS.

Arrangement of Transverses.	Maximum B.M. in foot-tons.	Maximum B.M. in terms of w and l_1.	Maximum B.M. in terms of w and l_2.	Maximum B.M. Ratios.
7—10— 7	31·30	$w \times l_1^2$	$w \times l_2^2$	1·183
		6·54	13·03	
8—10— 8	28·60	$w \times l_1^2$	$w \times l_2^2$	1·080
		8·02	11·98	
9—10— 9	27·60	$w \times l_1^2$	$w \times l_2^2$	1·043
		8·78	11·32	
10—10—10	26·48	$w \times l_1^2$	$w \times l_2^2$	1·000
		10	10	

w = Load on unit span.
l_1 = Length of end spans.
l_2 = Length of middle span.

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It will be noticed in the first three arrangements that the formula for maximum bending-moment, in terms of w and length of middle span l_2, bears a very close relationship to the formula for distributed load on a beam with fixed ends, *i.e.*, $\frac{wl^2}{12}$.

The modulus of section of longitudinal required to maintain, in this case, the same stress figures is 93·2, 85, 82, and 78·8 respectively, which means that a 17-inch channel is required for the bracketless ship as against a 15-inch channel for the ordinary Isherwood system.

TABLE II.

SHEARING FORCE AT THE ENDS OF BOTTOM LONGITUDINALS.

Arrangement of Transverse.	Shearing Force in tons.	Shearing Force Ratios.
7—10— 7	8·34	·760
8—10— 8	9·60	·875
9—10— 9	10·12	·922
10—10—10	10·97	1·00

TABLE III.

MAXIMUM DEFLECTION ON SPAN ADJACENT TO BULKHEAD

Arrangement of Transverses.	Deflection in inches.	Deflection Ratios.
7—10— 7	·008	·297
8—10— 8	·015	·555
9—10— 9	·021	·778
10—10—10	·027	1·000

On examination of the results given in Tables I, II, and III, it was decided, after careful consideration, that the 7—10—7 arrangement of transverses would give the best

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results without entailing any material increase in the weight of the vessel. It will be observed that although the maximum bending-moment is about 18 per cent. more than in the 10—10—10 arrangement, it will be taken care of by increasing the scantling of the longitudinal, so as to maintain the same internal stress on the longitudinal as in the other arrangements.

The principal advantage, however, is the considerable reduction in stress and deflection on the longitudinal in the vicinity of the bulkhead. For instance, the shearing force on the longitudinals at this part is 24 per cent. less than in the 10—10—10 arrangement, and causes a comparatively small stress on the plating between the toe of the bulkhead boundary bar and the end stiffener, equal to about $\frac{3}{8}$ of a ton per square inch, taking only one thickness of plating, or, in other words, clear of any liner; but of considerably more importance is the almost negligible amount of deflection on the span next to the bulkhead, amounting as it does in this case to only ·008 of an inch, or $\frac{l}{12,750}$ part of the span length, as against deflections of ·027 in the 10—10—10 arrangement.

The smallness of this deflection can be appreciated on considering that the deflection which is produced on the vertical stiffeners and side frames of a deep tank, in an ordinary cargo ship, is somewhere in the region of from $\frac{l}{1,000}$ to $\frac{l}{1,500}$.

Having relieved the ends of the longitudinals of a stress which is now transferred from the bulkheads to the deep transverses, the question arises of maintaining the continuity, or sufficient continuity, of the longitudinal material in way of the transverse bulkheads. This is obtained by fitting doubling liners to the shell and deck plating in the vicinity of the bulkheads. These liners in vessels under construction are fitted to every strake of bottom plating, to alternate strakes of side plating (the outside strakes), and to alternate strakes of deck plating.

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In the ordinary Isherwood system, the longitudinals are all cut in way of the transverse bulkheads, and are attached thereto by plate knees or brackets, the size and number of rivets in the bracket depending on the size of the longitudinal. The value of this bracket attachment, considered as a member contributing to the longitudinal strength of the vessel, cannot, we think, be determined exactly. It is generally agreed, however, that they are not equal to the tensile strength of the longitudinal, principally due to the eccentric pull that undoubtedly takes place in way of the brackets. They, however, fulfil their purpose to a great extent, and help to produce a ship immeasurably stronger than the transversely-framed ship.

It is well known that the transverse bulkheads deflect when supporting a pressure on one side of the bulkhead, the greatest deflection being, of course, in the region of the centre of the bulkhead area enclosed by the boundary bars. Therefore, all salient points projecting on to this area, such as the tips of brackets attaching longitudinal girders to the bulkhead, are subject to the straining effects of this deflection, more especially in the case of large brackets, such as used to be seen in the transversely-framed tankers. This deflection on the bulkhead produces a straining action round the tips of these bracket connecting angles which are more or less unyielding, and the tendency is to strain the rivets in the tips of the brackets, and also to open up the caulking round the edge of the connecting angle, causing leakage from one compartment to another, which is a serious matter when carrying different grades of oil. This trouble was almost eliminated by the adoption of the Isherwood system of framing, with its comparatively small and closer spaced brackets.

Nevertheless, as already mentioned, we felt that an improvement was needed at this part of the ship, and it was with this object in view that we were induced to look for some rearrangement of the structural members which would do away with

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these brackets, and still maintain the longitudinal strength of the vessel. This has been done, as already explained, and by the fitting of wide liners in way of the transverse bulkheads.

The sectional area of these doublings through the point of discontinuity of the longitudinals, is greater than the sectional area of the whole of the longitudinals, so it might reasonably be assumed that the longitudinal strength of the vessel, as a whole, is greater than a corresponding vessel in which the longitudinals are attached to the bulkheads by brackets, especially as these longitudinals have about 20 per cent. more sectional area than the longitudinals in the ordinary Isherwood system.

Particular attention has been paid to the riveting of these liners and of the riveting of the longitudinals themselves to the shell plating, as will be shown hereafter. It will be noted, in consequence of fitting these wide liners, that the usual bulkhead liners, equal in width to the boundary bars of the bulkhead, are deleted. It will readily be understood that butts of upper-deck plating, side plating, and bottom plating must of necessity be kept well clear of the transverse bulkheads, a minimum distance of, say, from four to six feet in a large tanker, if the longitudinal strength is to be maintained.

The shearing stresses on the rivets attaching the longitudinals to the bottom plating have been investigated, and are shown in Diagram E. It will, of course, be appreciated that the maximum stresses are at the intersection of the longitudinals with the transverses, and that these are at a minimum at a point midway between the transverses. At the parts of maximum stress the spacing of the rivets has been reduced. It will be observed that the sheering stresses on the rivets connecting the longitudinals to the bottom plating near the bulkhead are very low, due to the desirability of spacing the rivets closer in way of the shell liners, so as to develop the full

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benefit of the latter in preserving a sufficiency in the continuity of longitudinal strength.

The maximum stress on the rivets attaching the longitudinals to the bottom plating is about 5½ tons per square inch. This is at the intersection with the transverses, and rapidly decreases until in way of the liners the shear stress is only about 2½ tons per square inch, both stresses at their respective parts having in actual experience proved to be safe.

It might now be well to consider the deflection of the side of the ship and of a transverse bulkhead, in so far as the unsupported bulkhead attachment to the side of the ship is concerned.

The nearest analogous case in actual experience of a bulkhead attachment to the shell of the ship without the support of bracket attachments is that of a deep tank in the general cargo vessel with transverse framing and without side stringers. The deep tank is, of course, considered as being full, and without any corresponding support on the outside of the deep tank bulkhead, and the bracketless system has been considered under the same comparative conditions.

When we made the comparison, it was seen, in the case of the deep tank in the transversely-framed vessel, there was a deflection on the side frames of ·195 inch $= \frac{l}{1,300}$. In the bracketless ship the maximum deflection on the longitudinal frame is ·0165 inch $= \frac{l}{6,180}$, and on the side transverse ·0127 inch $= \frac{l}{17,800}$

In comparing these, it will be seen that the deflection in the case of the deep tank is very much greater than in the case of the bracketless vessel. From this it is apparent that, as far as deflection conditions at the boundary are concerned, the bracketless vessel is immeasurably stronger than a construction which is still adopted, and, if not perfect, is still

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performing its work. The conditions on the bulkhead are also equally satisfactory.

In the case of the deep tanks, the deflection on the stiffeners is ·287 inch $= \frac{l}{1{,}000}$.

In the bracketless ship the deflection on the bulkhead web is ·043 inch $= \frac{l}{7{,}400}$, and on the horizontal stiffeners ·0177 inch $= \frac{l}{5{,}750}$.

Here again deflection on the bracketless bulkhead is very much less than the deflection in the case of a deep-tank bulkhead.

See Diagrams J_A and J_B, which are for comparison purposes only.

In order to provide sufficient space for caulking the boundary bars of the bulkheads, the horizontal stiffeners on the bulkheads and longitudinals on deck, sides, and bottom have been stopped one-and-a-half inch clear of the toe of the boundary bars.

The question then arose as to what would be the buckling stresses and the shearing stresses on this small portion of plating. The buckling stress would be due to the compression on the bulkhead stiffeners when acting as a pillar supporting an end-on pressure, such as the outside pressure of water on the outside plating in the vicinity of the bulkhead, or in the case of deck and bottom longitudinals, the compression would be largely due to compressive stresses on the bottom and top sides, due to the vessel working in a sea-way.

The shearing stress on this small portion of plating has already been shown to be almost negligible, and on examination of the buckling stresses it was found that the factor of safety was about 30. Calculations were also made to ascertain whether the horizontal stiffeners on transverse bulkheads were strong enough, when considered as acting like

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pillars or struts supporting the outside pressure on the sides of the vessel in the vicinity of the bulkhead, and the result showed that it was of ample strength, the factor of safety being about 49.

Diagram H shows the calculations and illustrates the consideration of the transverse bulkhead as a strut supporting the outside pressure of water in the vicinity of the bulkhead, and comparisons are made with the factor of safety obtained in the deep-tank bulkhead and the ordinary watertight bulkhead of a general cargo vessel, from which it will be seen that the bulkhead in the bracketless ship is considerably stronger.

Owing to the necessary increase in size of the longitudinal in the bracketless system when compared with the ordinary Isherwood system, it will be seen that the vessel's longitudinal strength is considerably increased. Calculations show that there is an increase of about 10 per cent. in the case of the 430-feet tanker now building.

Whilst the elimination of the brackets connecting the longitudinals to the transverse bulkheads was the main reason for this new system of construction for tankers, it was, however, apparent that the elimination of all brackets as far as possible would be desirable, provided the strength of the vessel could be maintained without any undue addition to the weight of the structure. It was subsequently found, after careful consideration, that this could be done with the following exceptions, namely, the connection of the bottom transverses, upper-deck transverses, and second-deck transverses to the caulking side of the centre bulkhead, and upper-deck transverses in summer tanks to the trunk side.

It is obvious that the combination of side transverse, bottom transverse, and deck transverse is very much simplified when compared with the ordinary Isherwood system. The elimination of the brackets at the bilge and deck and centre bulkhead

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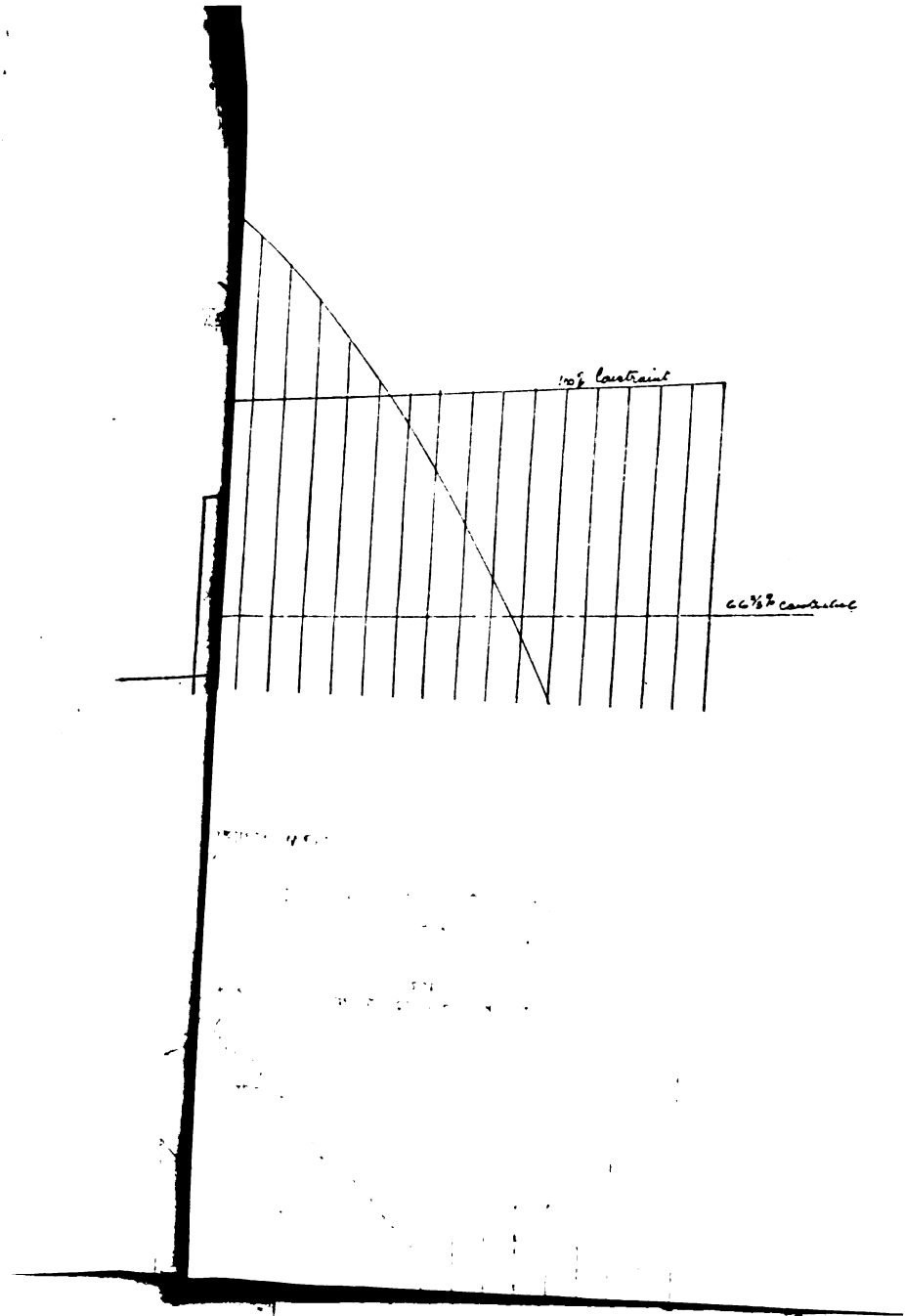

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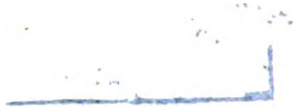

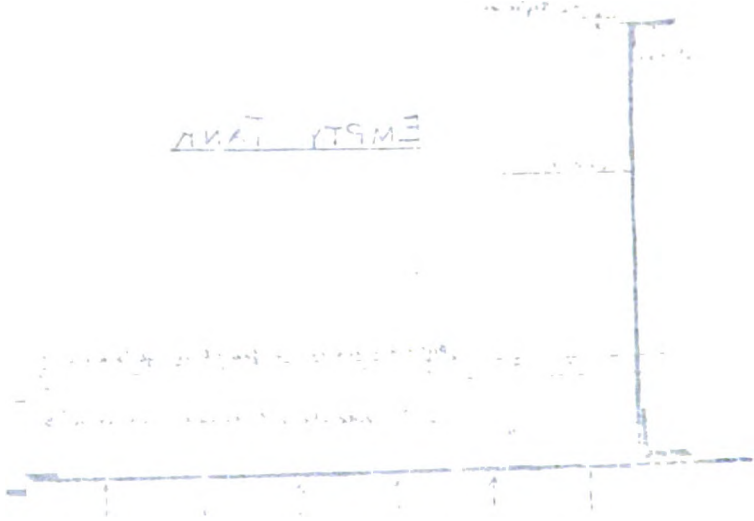

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on the stiffener side must result in a considerable saving in time and labour. The tripping brackets to side transverses, bottom transverses, and centre-bulkhead webs which are fitted in the ordinary Isherwood construction have been eliminated, and 12-inch bulb angles extending to the face of the transverses have been substituted, the whole transverse structure presenting the appearance of a substantial, strong, and workmanlike job.

It is usual in the ordinary Isherwood system to make the width of the centre-bulkhead web equal to that of the side transverses, but in the new system of construction it was felt that some reduction in width of the centre-bulkhead web was justified, in view of the transverse brackets fitted on the opposite side. Diagrams F_A and F_B which were prepared, showing bending-moments, shearing forces, and deflections on the centre bulkhead, indicate that this assumption was justified, and a reduction in width was agreed to.

The webs on the transverse bulkheads have a somewhat similar spacing to that of the side transverses, the ratios being $7\frac{1}{2}$—10—$7\frac{1}{2}$ or 3—4—3, so as to arrange for the webs to be riveted to the bottom and deck longitudinals.

The brackets or knees which in the ordinary Isherwood system are fitted to these webs have also been eliminated, and the webs made of sufficient width and thickness to give the necessary strength and stiffness, the shelf plates at the second deck being made of equal width so as to obtain an efficient connection at the head of the bulkhead web. The tripping brackets to webs have also been dispensed with, and a 12-inch bulb-angle stiffener carried to the face of the web substituted. A diagram, G, showing shearing forces and bending-moments, was also made for these webs, which proved the deflection of webs to be almost negligible.

Similar calculations were made for the horizontal stiffeners as in the case of longitudinals, and deflections were found to be so infinitely small that it could not possibly disturb the

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caulking of the bulkhead boundary bars. The end attachments of the bulkhead webs, side transverses, bottom transverses, and deck transverse have been made of ample strength so as to provide as far as possible for 100 per cent. of constraint.

The strength calculations generally made for a ship's structure do not, of course, give exact stresses and deflections. They are, however, useful for comparison purposes. It is common knowledge that a ship is an elastic and yielding structure wherein the supports to beams or girders are by no means rigid, and in the case of bracketed girders the amount of fixity at the ends is a very doubtful factor, the bracket itself having in many cases very little support or backing behind it. More often than not, in the case of large brackets, it serves the only purpose of transmitting considerable deflection from one part of the structure to another.

By the omission of brackets, it is, we think, possible to predict more closely what the actual stress will be on a girder. In the case of the calculations and diagrams A, B, C, D, for the longitudinals, the method of dealing with these is by Clapeyron's theorem, and assumes that the beam is supported only. This method, however, shows stresses that are, we think, in excess of what the actual stresses would be. It has, however, the advantage of providing for a further factor of safety, for it will be seen that the shell plating at A and D must offer some resistance to bending, and, therefore, sets up a certain moment of constraint at these parts, and again, the longitudinal at points of support B and C cannot be said to be in a similar condition to the Clapeyron beam, as it is securely attached to the transverse at these points.

It is interesting to note the variation in load on the two transverses due to the variation in spacing. Assuming w equals one-third of the external load on the ship's side and bottom for the length of one oil compartment, the load in terms of w is as follows:—

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TABLE IV.

LOAD ON TRANSVERSES IN TERMS OF w.

w = ONE-THIRD EXTERNAL LOAD OVER ONE OIL COMPARTMENT.

Arrangement of Transverses.	External Load in terms of w.
7—10— 7	1·195
8—10— 8	1·150
9—10— 9	1·130
10—10—10	1·10

As in the case of the longitudinals, it will be seen that by adopting the 7—10—7 arrangement it is necessary to put more material into the transverse than in any of the other arrangements to maintain the same standard of strength. This all goes to make the appearance of the whole framing very heavy and massive, and whilst possibly slightly heavier, a careful comparison with a vessel built on the ordinary Isherwood system shows the difference to be almost negligible.

Another interesting feature about the new system is the big reduction in number of pieces to handle. Anyone who has had experience in the building of oil tankers, both on the transverse system and on the longitudinal system, is well acquainted with the tremendous number of pieces to be handled, many of which are small and capable of being handled by one man, such as the smaller brackets and their connecting angles. The assembling of all the numerous small parts requires very special care and attention on the part of the foreman and others.

In the two vessels now building, there is a reduction in the number of pieces to be handled of about 36 per cent., which means, in the case of the 10,800-ton vessel, that a saving of about 5,500 pieces has been effected, whilst in the case of the 17,500-ton tanker there is a saving of about 7,600 pieces, these pieces, of course, being brackets and their connecting angles,

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Again, the amount of caulking and consequently the trouble in testing has been very much reduced. In the case of the 10,800-ton tanker now building, there is a saving of about 23 per cent., while in the case of the 17,500-ton tanker the saving is slightly more. Due to the elimination of all these brackets and connecting angles, there is also a substantial saving in very costly riveting. It is estimated that this saving will be about 7½ per cent. in the 10,800-ton tanker, and slightly more in the larger vessel. On consideration of what this saving means, it will be apparent that the cost of steel labour must of necessity be substantially reduced, and we have no doubt whatever that in the vessels now under construction the builders will bear us out in this statement.

Although no mention has been made regarding the structure outside the oil compartments, the same principle has, however, been adopted as far as possible in the vessels now building.

In the case of the side transverses in the engine and boiler-room, whilst the transverse space at the fore end of the boiler-room and after end of the engine-room was made about $\frac{7}{10}$ of the intervening spaces, thus dispensing with brackets at the ends of the longitudinals, it was found desirable to fit brackets at the top and bottom of the side transverses in these vessels, in order to reduce the width of the transverse, and so obtain more room for the main engines and auxiliaries.

The same principle of spacing the main members in order to eliminate brackets could also be adopted in the combination system of framing where the decks and bottoms are framed longitudinally and the sides of the vessel are framed transversely. The main transverses would be of similar scantlings, and spaced in the ratio of 7½—10—7½ or 3—4—3, in order to suit the spacing of the intermediate frames on the sides.

Horizontal girders would then be fitted between the transverses and attached thereto, and spaced in a vertical direction so that the intermediate vertical frames would be so supported

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that they would not require brackets to attach them to the deck and bottom. These girders would then be sufficiently strong to support the intermediate framing, and in turn transmit the pressure or load on to the transverse. The depth of these girders would be comparatively shallow, and would not extend to the face of the transverse, as in the web-frame system of construction. This system of construction would be slightly heavier than the longitudinal system.

As is usual with any new departure from accepted methods of ship construction, new problems arose, and new thoughts had to be brought to bear on them; several of them, after being carefully considered, produced an unexpected further saving in material and labour.

Take the cofferdams, for instance, which are usually about four feet wide. Here the shell and deck doublings run right through the cofferdams, and this produces a thickness of plating much in excess of that which would be likely to be required by classification societies for a frame spacing of four feet, and it was thought that most, if not all, of the longitudinals might be dispensed with in the cofferdams. Calculations were made, and it was found that many of the longitudinals could be omitted at this part, and this was agreed to and done. Again, in the ordinary Isherwood system many builders complained of the congestion of brackets on the transverse bulkheads in way of the bilge, involving as it very often did considerable effort to get these riveted up and efficiently caulked; also in way of the flat of floor forward, where the longitudinals are generally closer spaced, their attachments to the fore-peak bulkhead were in a similar congested condition, so much so that, in one particular case, a certain gentleman asked us if the vessel were intended to be an ice breaker. We might mention another case where the work is made much easier, that is the caulking of bulkhead seams in way of corner brackets on horizontal stiffeners. In many instances, lack of thoughtful consideration of the position of

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these seams led to difficult and inferior caulking in way of the corner brackets. It is now apparent that with the bracketless system the aforesaid difficulties and many other similar difficulties are eliminated.

It is very difficult to do full justice to a subject of this description within the compass of a paper which must of necessity be of a very restricted character, and we feel that we have barely touched upon the matter. A great deal more could be said, but time will not permit, and our desire has been to confine our attention to those aspects of this construction which we think will be of most interest to the members of this Institution.

In conclusion, we would like to express our appreciation of the honour which we feel it is to read a paper of this character before so important a society as that of The Institution of Engineers and Shipbuilders in Scotland, from the members of which we are now looking forward to a lot of valuable and helpful criticism.

Discussion.

Mr. J. Foster King, C.B.E. (Member): As on a previous occasion some 18 years ago, I have been granted the unexpected honour of an invitation to open the discussion on an Isherwood system. I was not prepared for it on this occasion, but can assure you, gentlemen, that it gives me a special pleasure to be the first of the members of this Institution to have the opportunity of expressing to Sir Joseph Isherwood and his son our appreciation of the importance of the paper which has been submitted for our consideration. The previous paper undoubtedly marked an epoch-making change in shipbuilding construction, and the present one certainly describes an important change in oil-ship construction. The authors have been good enough to let the mantle of prophet fall upon me, and I trust it will be worn with becoming humility. All

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Mr. J. Foster King, C.B.E.

the same, I cannot help feeling a certain pleasure in hearing someone say "He told you so."

Sir Joseph's work in 1908 was of very great value to British shipbuilding science, because prior to that time a large proportion of structural design was still wrapt in the mystery of the art of wood shipbuilding. Although the British Corporation Registry had for some years been practising the application of simple scientific analyses to the parts of the hull structure, such methods were not accepted nor adopted by the greater body of control. Sir Joseph's work, as I took occasion to point out in a paper recently read in Southampton, helped to lead all the societies towards consideration of parts of a ship in relation to their own particular work, rather than as being governed by mysterious emanations from longitudinal stresses of which nothing absolute was known. General shipbuilding practice may even have been more rapidly and more visibly affected by the introduction of the Isherwood system than by the meritorious efforts of a classification society. The present paper may have a similar stimulating influence through its publication of the acceptability of what, to many, may seem to be very unconventional methods of construction.

Sir Joseph made one big change, and others have been made which I have mentioned in this room, that do not pass into general practice as they should, because of the power of habit. For instance, it is difficult to understand, in connection with construction in general and tank work in particular (in face of familiarity with Isherwood wide-spaced, slotted transverse frames), why it is only in Sweden that shipbuilders cut away the faying flange of ordinary frames and stiffeners where they cross seams of plating. Efficiency having been proved, surely the avoidance of three-ply riveting, not to speak of weight reduction, more than justify some additional handling.

I am glad to see that the authors have definitely lost faith in brackets, and cordially echo some of their remarks. I trust that this paper and its practical application to ships under con-

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Mr. J. Foster King, C.B.E.

struction may lead the whole shipbuilding fraternity to realise that brackets are not always of their nominal value, and may easily be a detriment rather than a benefit to efficiency.

I do not profess, and dare not attempt in the time at my disposal, to analyse the extraordinarily comprehensive theoretical work which has been applied to the solution of the problem of placing the web frames so as to have uniform stress in the longitudinals. If presented to me, I should probably have contented myself with taking the established estimate of $\frac{wl^2}{16}$ as a measure of the span between the webs and $\frac{wl^2}{12}$ for that which is not attached at one end. This would give a spacing ratio of 10 to 7½, or practically that which has been achieved with great labour, and one which has the safe support of experimental evidence.

I think I have always been somewhat at difference with Sir Joseph with regard to the longitudinal value of material which is devised to support the webs and flanges of the main girder, because of my belief that the supported material is that which withstands longitudinal stress, and that the supporting framework, no matter how disposed, should be considered on its own merits in relation to its own work and not as part of the shell. The reverse of the latter is the original conception which obtained in wood shipbuilding days, and one whose persistence has most seriously retarded the development of shipbuilding science.

Without arguing the relative merits of longitudinal and transverse disposition of the framing, it must be admitted that, under low stresses and under compression, a longitudinal disposition of such material does reduce the effects of strain on the main structure, and that the shell doubling which is fitted round the bulkhead does give a certain continuity of area in that direction, if it is worth giving. I would regard the doubling, however, as of more value as a means of meeting the effects of deflection—effects which have to be met even

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if they are only of the order of $\frac{l}{1,000}$ mentioned by the authors. My experience scarcely bears out the probability of finding such small deflections in ordinary ship design, where $\frac{l}{400}$ is regarded as good, although I have experience of the higher standard. With deflections of any order, however, there must be continuous alternating stresses at the ends of the unattached stiffeners of a character which has been known, on occasion, to have caused fracture in plating where there was no reason to expect abnormal deflection. These considerations suggest that experience may show the desirability of fitting a doubling round the rim of the bulkhead plating as well as on the shell.

The major aspect of the paper, from the practical point of view, is its exposition of the great gain in economy and efficiency of oil-tight construction to be obtained from the elimination of the enormous number of pieces which are fitted round the bulkhead, in the form of brackets and attachments. I hope that when Sir Joseph completes his information, he will let us see that he also eliminates the brackets at the junctions of the transverses. (Sir Joseph here exhibited a midship section which showed that this had been done.) This is a decidedly improved point of view, as there is no doubt in my mind as to the superiority of deep webs without brackets over shallower webs with brackets, as I have demonstrated by speech and practice during many years.

It has scarcely been possible to deal with the purely theoretical part of the paper in the time which has been at the disposal of the readers of the paper, but it is to be hoped and expected that some of those who are more accustomed to the differential calculus will have a good deal to say on the subject.

I again desire to express my appreciation of the paper and the practical importance of that which it contains.

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Mr. T. R. Thomas, B.Sc.

Mr. T. R. THOMAS, B.Sc. (Member): May I express my thanks to the authors for such an interesting and valuable addition to the Transactions of the Institution? While I fully appreciate the advantages of the adoption of this suggested simplification of the Isherwood system of construction, I should like to suggest to the authors that the method adopted to fix the position or spacing of the transverses is one which is very liable to give results, the accuracy of which will be greatly influenced by the validity of the assumptions made. For instance, the assumption is that the transverses are purely points of support, and reference to Table I shows that the maximum bending-moment in terms of the middle span is $\frac{wl_2^2}{13{\cdot}03}$. If, however, it be assumed that the transverse is a point of fixity, this maximum bending-moment becomes $\frac{wl^2}{12}$ —evidently a worse case for the ship. It is also noted that the conditions assumed would indicate a certain twisting effect on the transverse, as reference to Diagram A shows that the point of contraflexure is not at the transverse. If the assumption of support can be shown to be dangerous when made in connection with the transverses, it is surely doubly so at the bulkhead, where so much is done to compensate for the breaking off of the stiffener. My object in raising these points is really to draw attention to the danger of using such methods, except to confirm the dictates of experience. I suggest that the authors might have tackled the problem by assuming the beam continuous over the bulkhead and applying the theorem of least work. The results, however, might not differ much from those they have obtained, and are liable to much the same inaccuracies. One serious objection to such methods is that any deflection of the transverse, however slight, nullifies the whole calculation.

It is interesting to note that the British Corporation have for some years past been familiar with a system of construc-

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tion for oil tankers in which use is made of deep girders. No brackets have ever been fitted at the ends of these, and they have proved entirely satisfactory. They have, however, been of such depth and proportions as to render them free of any measurable deflection.

The comparisons made with the ordinary deep tank are, I think, not quite sound, for the reason that the ordinary deep-tank framing system might be justly referred to as the Isherwood system turned through 90 degrees, and comparisons should, I suggest, be made at relative portions on the bulkhead. For instance, it could be shown on the lines indicated in Diagram H that the lower edge of the transverse bulkhead is superior to the same edge of the Isherwood bulkhead.

Mr. JOHN ANDERSON (Member of Council): This paper describes an extension of a system of ship construction which has been in practice for the last 18 years. The story of the introduction of the Isherwood system has been very simply told in a few words on the first page of the paper, and the fact that vessels representing 12¾ million tons carrying capacity, which is about 15 per cent. of the world's production during the period in which this system has been operative, is, I think, a very eloquent testimony to the superiority of that system for vessels carrying oil or other liquid cargoes. The authors' paper deals with a very important development of that system, and the points dealt with have been so lucidly described that it is unnecessary for me to raise any questions.

I believe this development to be on the right lines for improved workmanship, and the elimination of brackets is certain to give a better distribution of material. I have had experience in the construction of only one oil tanker, and cannot, therefore, speak with authority, but the design of large deep tanks in ordinary vessels makes an almost analogous problem. I am aware that Mr. Thomas has said it is not so, but I still believe it is an analogous problem, and, so

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Mr. John Anderson.

far as I have seen, the success of such design is largely dependent upon securing, as far as possible, a homogeneous distribution of material. In these designs it is often found that any concentrated reinforcement, if not very properly tapered off, is almost sure to give trouble. From a practical point of view this innovation also offers many attractions, as the elimination of brackets and their connecting angles dispenses with a large number of parts which were troublesome to adjust, while the adoption of doublings at the ends of the longitudinals does not seem to represent any appreciable increase over the diamond plates otherwise required. The diagrams accompanying the paper make an interesting study, and are sure to be used as models for future work of a similar nature. I would just like to congratulate Mr. William Isherwood, who, I understand, is responsible for these diagrams, on the large number which accompany the paper. The only figure upon which I should like information is that used for the modulus of elasticity, namely, 10,000 tons. I am aware that the authors have said that all calculations in connection with ship structures are only relative, and that the one I have named may have been adopted as an arbitrary one. I do not question the figure they have given, but I am very much interested to know if it has been deduced from any practical experiments made by them. I would like to know if they anticipate any appreciable saving in weight of material by this development; it is conceivable that the nett weight of the vessel will be somewhat increased, whereas the invoiced weight, on the other hand, may be reduced. Like Mr. King, I do not propose to discuss the mathematical deductions, but I feel that as experience advances it may be found advantageous to adopt a somewhat different spacing, possibly a 6—12—6 distribution, or something between that and the 7—10—7 presently suggested. I would not be afraid of the results of deflection between the two transverses, and would be inclined to distribute these transverses more in the way I

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have suggested, with a view to having less load on the ends of the longitudinals in way of the bulkheads.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Member of Council): Beyond congratulating the authors upon the bold step of eliminating the brackets which shipbuilders inherited from the woodworkers of old, I do not propose to say very much, but will plunge right into the middle of the argument, which Mr. King refused to do. Firstly, I would like to read an extract from Prof. Perry. In introducing the subject of continuous girders, Prof. Perry says: "For some time railway engineers made use of continuous girders. It is easy to show that, if we can be absolutely certain of the position of the points of support, continuous girders are very much cheaper than separate girders. Unfortunately, a comparatively small settlement of one of the supports completely alters the condition of things."

Consider how closely the position of the points of support on the transverses may be expected to coincide with the theoretical positions assigned to them. Liners or packing pieces are not unknown in ships. No ship is ever the length or the depth that it is supposed to be, and I for one do not for a moment believe that the transverses will be set up exactly in the positions that they should be. Therefore, I think that any closely argued spacing of transverses or strengths of longitudinals will be entirely vitiated by these inevitable inaccuracies of workmanship. The omission of brackets is all to the good, from the practical point of view. In quite a number of cases they have been omitted, and limited experience has shown that the omission does no harm; it rather appears to do good. Consequently the adoption of this system is welcomed, and if it stands up, as I have not the slightest doubt it will, then it will be adopted wholeheartedly, but not for the theoretical reasons given in the paper. In connection with the arguments, I have so far failed to understand—my

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Mr. W. H. Riddlesworth, M.Sc., M.Eng.

stupidity, I presume—what the authors mean in the paragraph at the bottom of page 620, where they speak of the difference between support and fixity for the longitudinals on the transverses. It is not clear to me what is meant, and I shall be very much obliged if some further explanation can be given.

As regards the method of attacking the problem, I imagine it is not beyond the skill of the authors to determine exactly the best position for the transverses by an algebraic process which would eliminate most, if not the whole, of the laborious diagram work. On page 622 the authors say, "Although it must be obvious that there must be a certain amount of fixity or moment of constraint at the points A and D, the beam has been assumed to be simply supported at these points." It is really very difficult to see how any amount of riveting attachment to a flat plate can transmit any appreciable bending-moment to the longitudinals. Next, considering the deflections that have been worked out, what about the deflection due to shear? The deflection of a deep beam due to shear is not negligible, and I shall be very much obliged if the authors can say whether any attempt has been made to estimate it. Lastly, so far as it appears the transverses have been assumed to give a rigid support to the longitudinals, but is this the case? They are obviously less rigid than the main bulkheads, and it is probable that an investigation of the deflection in them would considerably modify the authors' conclusions about the deflections near the bulkheads.

Mr. H. A. M. NAPIER (Member): I have not had any experience of the Isherwood system, but from the practical point of view I am very glad to see the omission of brackets so strongly advocated. The authors say that the longitudinals stop 1½ inch clear of the toe of the transverse bulkhead bar, which is probably four or five inches deep. It does not seem clear to me that the longitudinal can be said to be supported at the point of intersection with the bulkhead

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The diagrams show the deflection of the longitudinal as being continuous right up to the point of intersection, but there is a gap of possibly six inches or more at that point. Certainly the doubling comes in there, but it would be interesting to have more information concerning the stresses that are liable to be set up at that gap.

Mr. JOHN E. IRVINE (Member): With reference to the cutting of stiffeners 1½ inch back from boundary bars, this is dealt with in the paper from the point of view of the stiffener acting as a pillar resisting an end pressure; but if the stiffener is considered as a beam with a pressure on the other side of the bulkhead, would the cutting away of the stiffeners at the ends not have the effect of considerably increasing the deflection of the stiffeners, with consequent excessive bulging of bulkhead plating?

Prof. PERCY A. HILLHOUSE, D.Sc. (Vice-President): This paper seems to me to put the shipbuilder very much in the position of a patient. When a man becomes very ill he consults a doctor, and as the centuries pass what the doctor recommends one century is what the doctor tells you not to do next century. One man's meat is another man's poison. The meat of the shipbuilder of one generation is the poison of the shipbuilder of the next generation. In the old days very heavy stringers were found in the holds, and very great attention was paid to them. They were thought to be absolutely essential to the strength of the ship. Then someone came along and discovered that heavy stringers in the holds were not essential, were in fact a drawback, and they disappeared. Just the same thing now obtains in oil ships. For years it has been thought that no oil ship could be a success unless she had brackets, and a great amount of care was lavished on the design of these brackets. Now we are told that they are no good, and that it is better to do without them.

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Prof. Percy A. Hillhouse, D.Sc.

I am not a prophet, and I do not know what the next development will be, but it is almost certain that if anything is very much insisted on as being absolutely essential it would be a very good thing to take out a patent for leaving it out.

I presume from the trend of the paper that the authors intend that the longitudinals shall in some way contribute to longitudinal strength; that is, that there is a fore-and-aft pull in the 17-inch longitudinals which is transmitted past the transverse bulkhead *via* the shell plating. The lines of stress in the longitudinals on approaching a bulkhead must apparently concentrate towards the outer or shell flange of the channel, pass then into the single row of rivets connecting the channel to the shell and doubling, spread out fanwise over the shell plate and doubling until they pass the bulkhead, concentrate on the other side and pass *via* the connecting rivets to the outer flange of the longitudinal in the next hold, and finally distribute themselves uniformly over the channel bar. This is quite a gymnastic feat to expect from the stress-lines, and its performance will be watched with great interest.

Mr. Simpson, I understand, will later on give a number of practical details concerning the bracketless system. He has been engaged in building such a ship, and one thing of paramount interest would be to hear what is the saving in cost due to the great reduction in the number of pieces to be handled. The saving in the handling of five, six, or seven thousand different pieces is one which every shipbuilder must look upon with favour, and I am sure it must mean a great reduction in the cost of building.

Prof. T. B. Abell, O.B.E., M.Eng., and Mr. D. B. Gebbie (Member): The methods of securing the heads and heels of stiffeners have been examined very closely of late years, commencing perhaps with the work of the Bulkhead Committee. Their tests made it quite clear that it was extremely difficult to secure, by any simple and commercial arrangement

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of attachments, the full strength of a stiffener at the bottom of a bulkhead. The failure of bulkheads was shown to be due ultimately to the failure of the end rivets, sometimes those attaching the stiffener to the plating, sometimes those attaching the brackets to the tank-top plating or to the stiffener itself. The first method of remedying this defect was to increase the size of the brackets and to increase the riveting also, but this did not give a complete remedy. This seems to have been the experience of the authors also, for they state that, even with the very large brackets to the stiffeners in oil tankers, it was not always practicable to render the riveting secure. This must have been particularly the case at the forward end of the ship, and, as a matter of fact, has come under our notice.

An alternative method was then suggested of dispensing with brackets or lugs to stiffeners entirely, and attention was drawn to this method in a paper read before the Institution of Naval Architects. By suitably shaping the ends of the stiffeners, it was practicable to relieve the end rivets of the stiffeners without sacrificing the general efficiency of the stiffened plating. Experiments were carried out to verify this point at the University of Liverpool. These showed that a plate, nominally 0·4 inch thick, stiffened with angles 4 inches × 3 inches × ·34 inch, with ends snaped at 30 degrees with the flange, but connected only to the plate, when subjected to a head of 70 feet, would experience a stress of 12 tons. If the plate had been unstiffened the stress would have exceeded the elastic limit, and if the plate had remained elastic the stress would have reached 24 tons. If attempts had been made to secure the ends of the stiffeners by brackets or lugs at the ends of the stiffeners, the rivets attaching would in all probability have failed.

The authors have gone a very great step further by a most ingenious spacing of the main transverses of the ship, and also of the main vertical stiffeners of the transverse bulkheads

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This has relieved the ends of the stiffeners to a very large extent of the bending-moments created by the normal fluid pressure, and has enabled them to dispense with brackets or other subsidiary means of end attachment. We say to a very large extent because it is not practicable to relieve the structure of all bending-moment at the bulkheads by the means proposed, unless the plate itself is actually severed. For all that, the method suggested is the best that can be found in practice. The authors have spaced the main transverses in accordance with the theorem of three moments for a "continuous" beam whose length is that of the oil hold, thus assuming that the plating is cut at the bulkheads bounding the hold, and that the structure is just supported at the bulkheads and not constrained. The result is that, as will be seen from the curves of deflection in Diagrams A, B, and C, the plating on each side of a bulkhead will make a definite angle the one with the other; since actually the plating is not severed and is continuous over the bulkhead, there must be a bending-moment in the plating at the bulkhead. For there cannot be a definite angle, as the curves of deflection show. Of course, these curves are only used to demonstrate the deflection under the conditions assumed, and not those actually obtaining. The magnitude of the bending-moment in the shell plating at the bulkheads will depend upon the stiffness of the shell stiffeners, and will be greater the greater their stiffness. It will be less if the stiffness of the shell stiffeners is decreased by snaping the ends. This will relieve the end rivets, and also the stress induced in the plating. Whilst, therefore, the new spacing of the main transverses relieves the bending-moment at the ends of the stiffeners sufficiently to dispense with the end brackets, and although there will certainly be some bending-moment in the plating at the bulkheads, there should be no difficulty, provided the end attachments are well designed. We are, however, confident it will be worth while considering very

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carefully whether the degree of snaping of the stiffeners shown in the sketches is sufficient to prevent failure of the riveting. If failure is to occur at all, it will certainly occur at this point, and it may be desirable to increase the angle of the snape in order to distribute more evenly the stresses on the last three or four rivets in the stiffeners. We imagine the other practical problem which experience will have to decide is whether it will be better to increase the number of stiffeners in order to secure more rivets at the ends rather than to increase the stiffness of the shell stiffeners. We feel that the method is undoubtedly one in the right direction to avoid rivet trouble, and expect that it will meet with success.

The brackets of the normal Isherwood system performed a further function by securing, in some measure, longitudinal continuity of the shell stiffeners, which then could be reckoned as contributing to the longitudinal strength of the ship. Omission of the brackets, therefore, requires compensation if the strength, with brackets, is to be maintained. This compensation has taken the form of doubling plates at the bulkheads, a very simple and a practicable arrangement. The conditions of the plating in way of the compensation are, however, very different from when the brackets were fitted. When the bottom plating is under compression from longitudinal bending, there is now a short length of plating, measured, in the fore-and-aft direction, lying between the bulkhead boundary bar and the end rivet of the shell stiffener, which is quite unsupported by any stiffener, and which must act as a pillar taking the end thrust of the compressive load. It appears that the length of this unsupported plating, including the doubling, is at least 5 inches, made up of half the width of the boundary bar, 2 inches, the clearance for caulking, 1½ inch, and the distance of the end rivet from the end of the stiffener, 1½ inch. This plating will also experience a bending-moment in the transverse plane because of the distance of the end rivet, 7 inches, from the bulkhead (see the

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curve of bending-moments; the bending-moment is assumed to be zero at the bulkhead). The pillar is, therefore, eccentrically loaded. However, it is very difficult to suggest any other form of compensation, but here again shaping of the stiffener will reduce the liability to failure at this critical position. The ideal arrangement would be to weld the stiffener across the flange to the shell plating, and also to weld the boundary bar to the shell plating.

We need not enlarge upon the many practical advantages which the introduction of this system will provide, or the economies which will result from its use; they are very clear—the greater access to the bulkheads for caulking, the reduction of labour involved by the omission of the end brackets, which require very careful fitting if defective riveting is to be avoided, the reduction in the amount of riveting, improved facilities for inspection of the parts most severely stressed and most liable to defects, reduced cost, therefore, of maintenance, the reduction in the number of parts, and the greatly simplified construction. All these factors contribute to make the system an ideal one, and one that we feel will meet the needs of the moment. We should like to share in the congratulations which, we are sure, Sir Joseph will meet with from shipowners and shipbuilders alike.

Dr. A. M. Robb (Member): It is unfortunate that the good case for the elimination of brackets should be covered up by a mass of unsound reasoning, and I suggest that the fundamental fallacy lies in the assumption that longitudinal framing has any connection whatever with longitudinal strength. If the framing members contain more material than is necessary for their function of stiffening the shell, *the excess material* (assuming that its extent is calculable) *may* be taken into account as longitudinal structural material, but such material is not being used to the best advantage, since the proper place for longitudinal structural material is

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Dr. A. M. Robb.

in the containing shell of the box girder that a ship is. The whole argument thus summarised is very fully developed by Mr. William John in a series of papers to the Institution of Naval Architects, including one to a joint meeting with this Institution, in the period 1877-1880, and the general principle underlying the disposition of framing is stated in these words:—

". . . it is easier to impart strength to the sides by spanning the short distance between the rigid iron decks and rigid bottom than by spanning longitudinally the whole length of a ship's hold."

This argument is not invalidated by the fact that the oil tanker with closely-spaced bulkheads is a type of ship whose development was not foreseen by Mr. John. The general argument still holds good, and its application to the particular case of the oil tanker indicates that longitudinal framing is a matter of convenience because of the close spacing of the bulkheads.

Even if it be assumed that longitudinal framing is a factor of importance in the consideration of longitudinal strength, the claim that the bracketless ship is about ten per cent. stronger than the ordinary Isherwood ship is radically unsound. Throughout the paper there runs a sort of Grecian chorus chanting "continuity of strength," as if mere sectional area of material were the one thing that matters, whereas it is effectiveness of connection that matters. For example, the longitudinal in Diagram E has a sectional area of more than 15½ square inches, and so has an ultimate tensile strength of about 440 tons per square inch. This longitudinal can make connection with the continuing longitudinals before and abaft it only by virtue of the doubling plates at the bulkheads. And each end of the longitudinal is anchored only by eight ⅞-inch rivets, whose total shearing strength is in the region of 104 tons per square inch. That does not look much like "continuity of strength," and there is not even a doubling at every strake of plating.

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Dr. A. M. Robb.

As a minor constructional point, I am interested to learn whether the deflection of the side longitudinals after erection, when they are hanging in space with their least depth vertical, will not be so great as to introduce difficulties when the time comes for the fitting of the shell plates.

Mr. JAMES B. CRAWFORD, B.Sc. (Member): I am very pleased to have an opportunity of taking part in the discussion on this interesting paper, particularly as I was associated with Sir Joseph in the construction of the first Isherwood vessel built on the Clyde, which was also the first general cargo vessel ever built on this system.

Those who have had experience of the Isherwood system must be aware of the difficulties in fitting, riveting, and caulking the brackets and connections in the bilges, and also forward and aft. This work is always awkward, and does not lend itself to good workmanship. Therefore, the bracketless system, in which this can be eliminated, is very welcome. I am looking forward to the publication of the results of the tests carried out on the North-East Coast to prove that the calculations so ably put forward in support of this system are substantially borne out by practice.

With the bracketless system, special attention will be necessary at several points. The riveting in way of the bulkhead frame and shell and doublers will be three-ply. The omission of brackets will make the operation of framing more difficult, but no doubt this can be easily surmounted. Regarding the working of the end rivets of the brackets in the ordinary Isherwood system, I have on several occasions arranged the bracket so as to bring two end rivets into play instead of one.

The authors believe that they are the first to use Clapeyron's theorem in shipbuilding investigation, but it is used quite frequently in caisson and floating-dock design.

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Mr. J. McGovern: If we are to retain our maritime supremacy, the present moment is most opportune for a full and careful investigation of any new ideas bearing on improvements which may be effected in the design, construction, or maintenance of our ships. The Institution is, therefore, to be congratulated on having this valuable addition to its Transactions, as it describes a distinct evolutionary step in ship construction. The success which has followed upon the adoption of the longitudinal system, developed by Sir Joseph Isherwood to overcome existing deficiencies at its inception, will undoubtedly ensure the focusing of attention on his latest proposal, embracing as it does several unique features.

The reduction in the number of parts to be handled, with the consequent saving in riveting and caulking, and the elimination of difficult work in confined spaces, are features which will commend themselves to all shipbuilders as a distinct aid to speedy and more economic construction, provided these balance the increased weight involved by the heavier transverses, longitudinals, and additional doublings, for in many cases two transverses will now be required where only one was fitted in the usual bracketed system. It is perhaps a moot question as to whether the erection of longitudinals and plating (if the templates for the latter are lifted in the ordinary way) will be as satisfactory as in the usual longitudinal system, owing to the absence of connections at the bulkheads. It is to be hoped that during the discussion the views of the builders of the vessel under construction on this system may be forthcoming.

The new system has many features to recommend it, from the shipowner's point of view, as regards the question of maintenance and repairs, particularly should damage occur, as the presence of so many brackets under the ordinary longitudinal construction always involves considerable expense for repairs and renewals.

The service performance of vessels built on this system

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Mr. J. McGovern.

will be keenly followed by all interested parties, and there is little doubt that the experience gained will automatically result in its universal adoption, particularly for oil tankers, in a similar manner to the Isherwood system from which it has sprung.

Special thanks are due to the authors for the thorough manner in which they have put forward their strength investigations which accompany the paper. The solution of the problem by the use of Clapeyron's Theorem of Three Moments is akin to that frequently adopted when considering the strength of deck girders, supported by pillars and bulkheads, and is the customary method of ascertaining the bending-moments at the head and reactions at the pintles of balanced rudders.

Mr. THOMAS S. SIMPSON: As this is a theoretical paper, possibly a few remarks on the practical side of the new system may be of interest. To assist me to show the simplicity of the structure, illustrations are given of two vessels actually constructed on the different Isherwood systems, Figs. 2 to 14.

In the first place, it is most desirable that the midship body be continued fore and aft as far as possible, and in my opinion this form can be carried for practically the whole length of the oil-carrying compartments; then the main deck sheer should be dispensed with so as to make the oil-tank bulkheads and the transverses uniform for the whole of this distance. Whilst it is not essential to maintain a uniform spacing of transverse bulkheads over the length of the oil tanks, it will be appreciated that it is desirable to do so in order to secure uniformity of work. I may say that these recommendations are also of advantage in the ordinary bracketed Isherwood tanker, but much more so in the bracketless vessel where all the brackets are eliminated, as there is a larger saving on template work.

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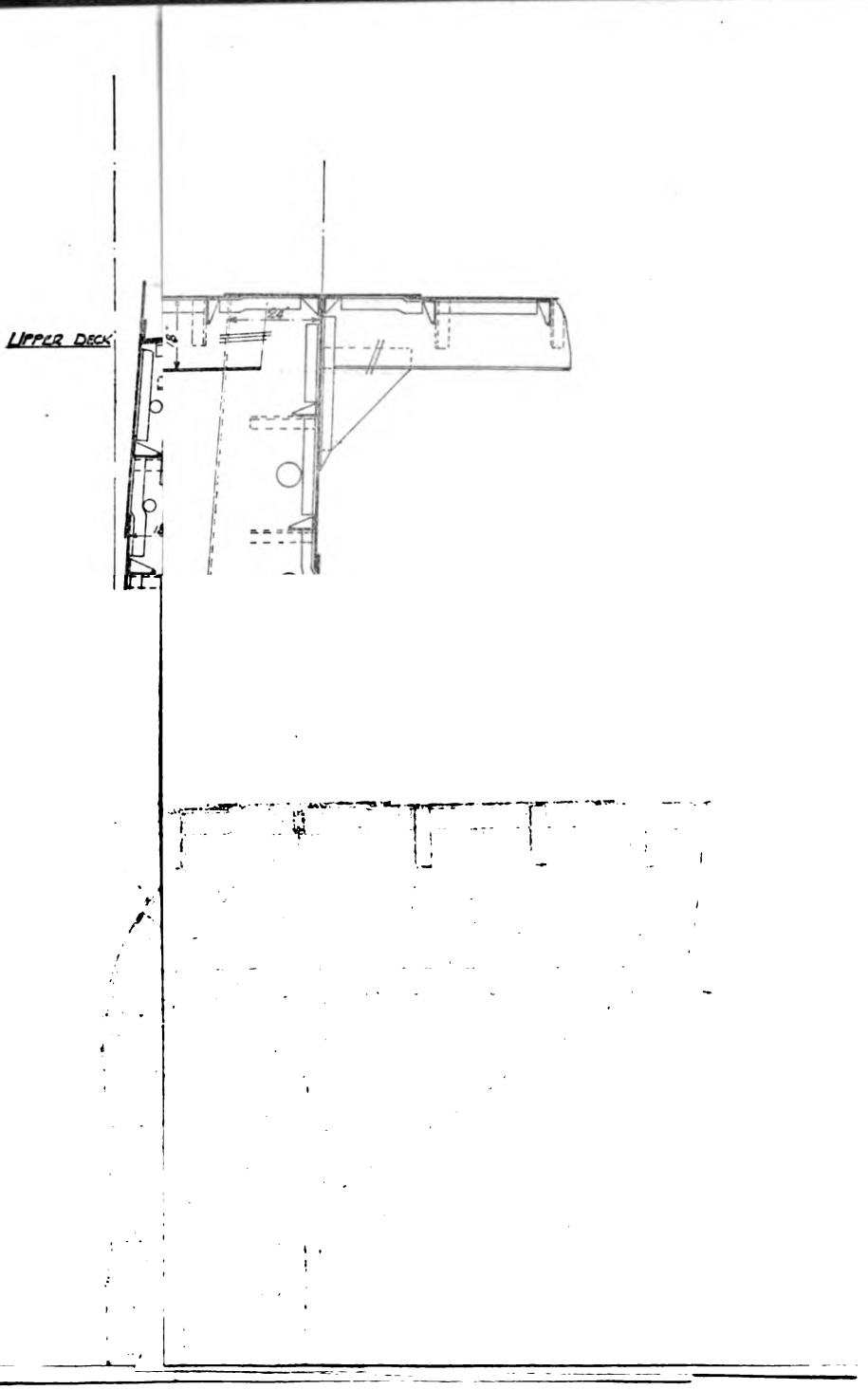

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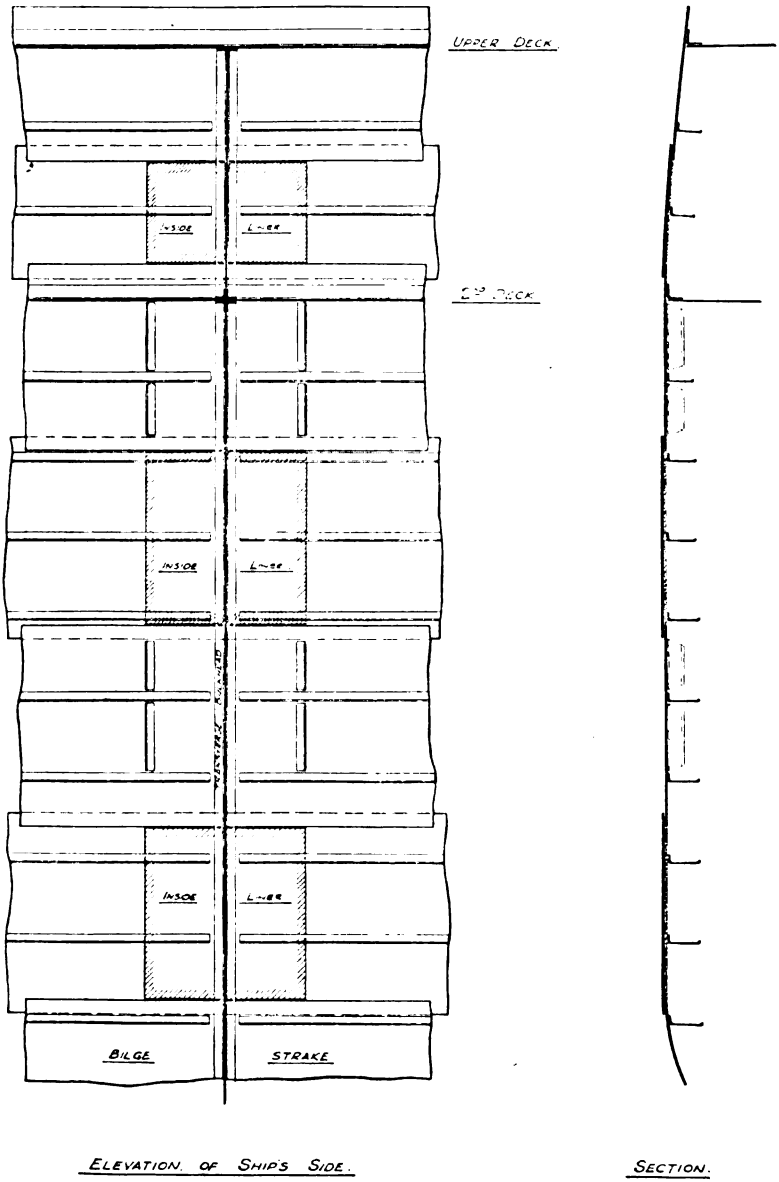

Fig. 8.—Showing Liners in way of Oiltight Transverse Bulkheads (Bracketless System).

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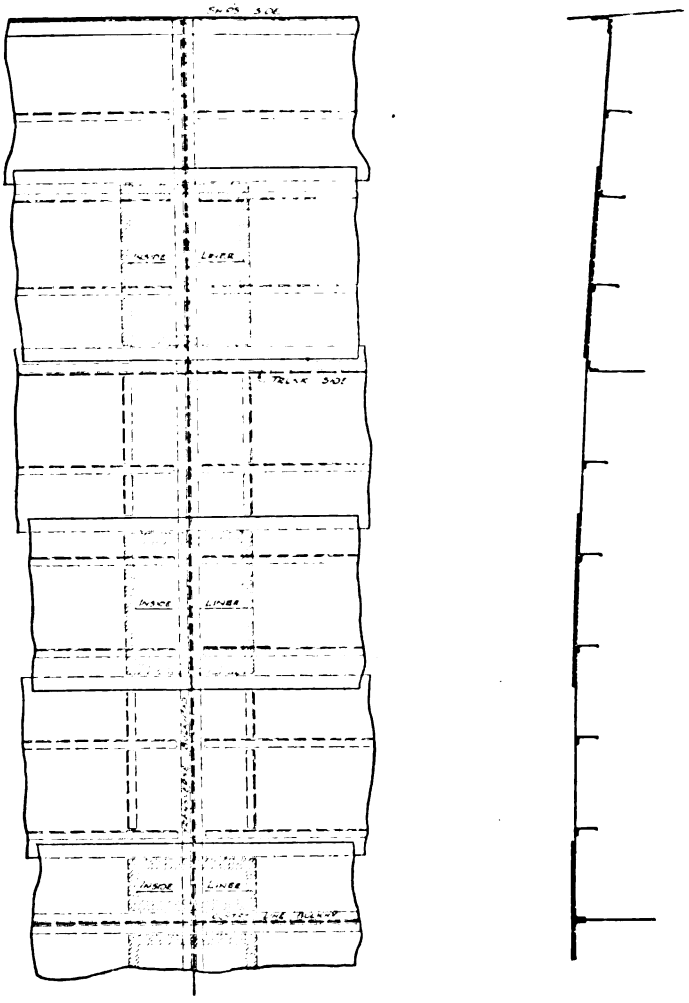
Mr. Thomas S. Simpson.



PLAN VIEW OF UPPER DECK. SECTION.

Fig. 9.—Showing Liners in way of Oiltight Transverse Bulkheads (Bracketless System).

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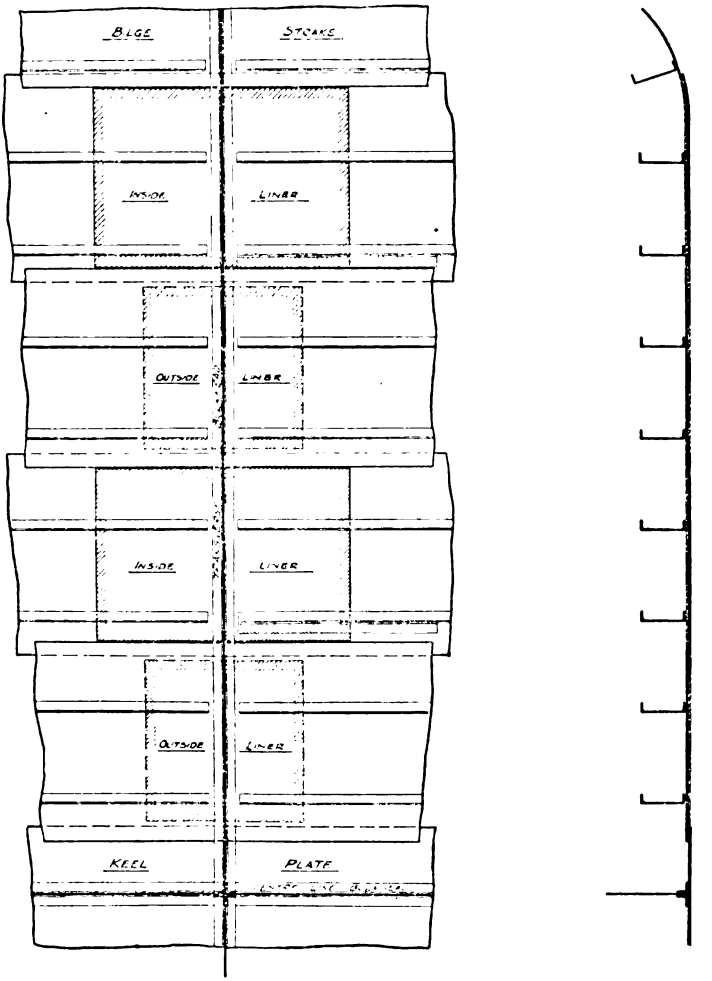

Fig. 10.—Showing Liners in way of Oiltight Transverse Bulkheads (Bracketless System).

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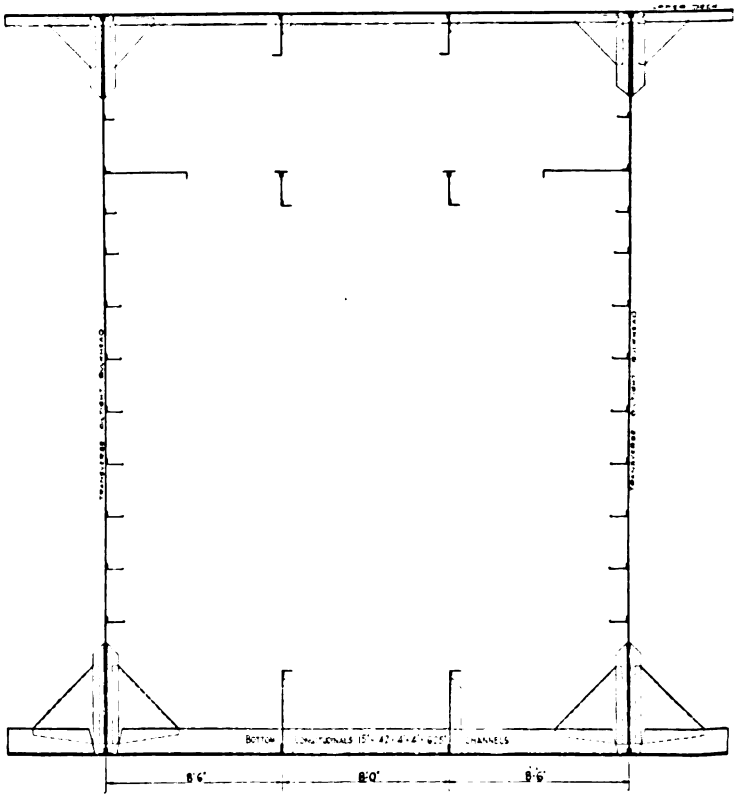

Fig. 11.—Elevation showing Framing in Tank (Isherwood System).
Dimensions of Vessel: 440′ B.P. x 56′9″ Mld. x 33′11″ Mld.

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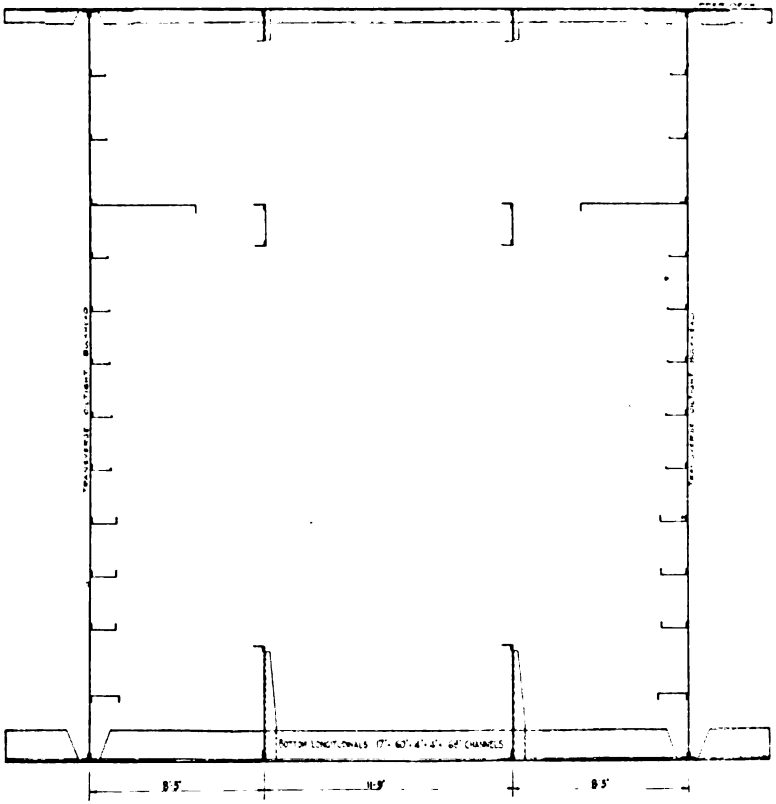

Fig. 12.—Elevation showing Framing in Tank (Bracketless System).
Dimensions of Vessel: 430' B.P. x 57'8" Mld. x 34'3" Mld.

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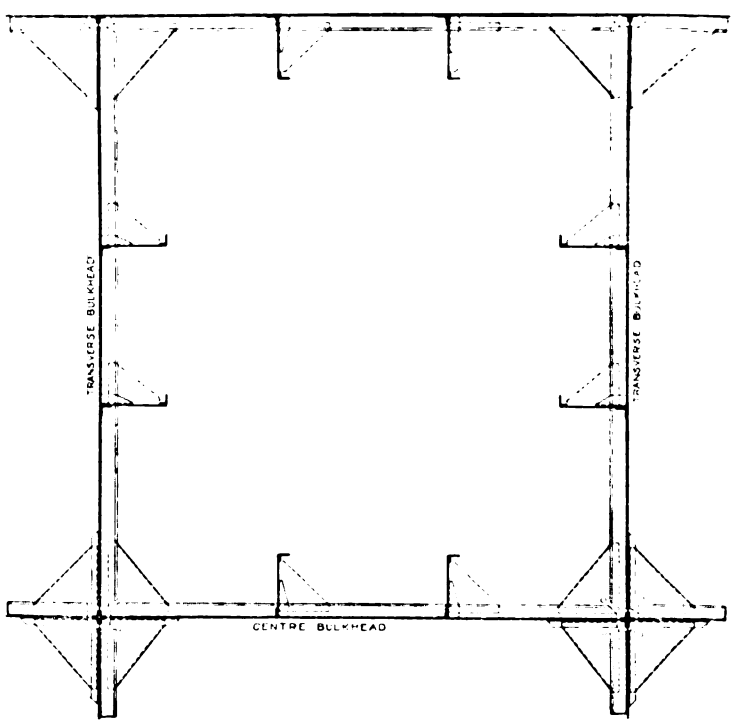

Fig. 13.—Plan View showing Framing in Tank (Isherwood System).
Dimensions of Vessel: 440′ B.P. x 56′9″ Mld. x 33′11″ Mld.

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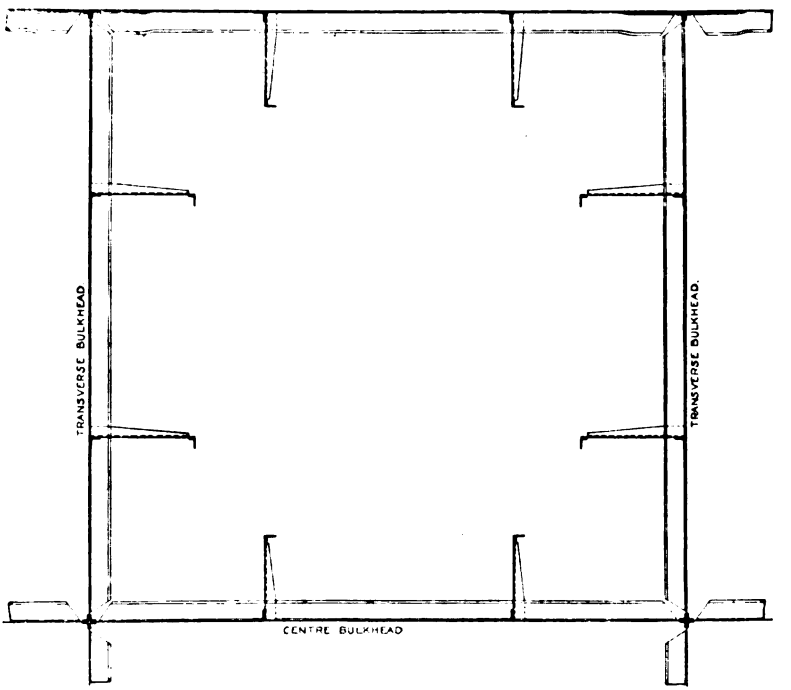

Fig. 14.—Plan View showing Framing in Tank (Bracketless System).
Dimensions of Vessel: 430′ B.P. x 57′8″ Mld. x 34′3″ Mld.

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Mr. Thomas S. Simpson.

The bulkheads are plated with horizontal strakes, the plates extending in one length from the centre line bulkhead to the ship's side. The centre-line bulkhead is also plated horizontally with plates the full length of the tank, the whole being connected by four single-riveted angles at the centre line, thus dispensing with the much discussed cruciform plates. These plates with their stiffeners can be put across the riveting skids, plate by plate, and riveted, and once erected the troubles of the foreman plater are at an end, as the omission of the many hundreds of brackets and bracket connections makes the work of plating, riveting, and caulking very easy.

Work on the longitudinals becomes simplicity itself, with the exception of the 17-inch channels on the bottom, where they have to be set over the large bulkhead liners, Fig. 15. Care is required to keep the set of these channels as short as possible, so as to avoid the fitting of a too long tapered liner, which is objectionable. Considerable saving is also effected in the erection of the longitudinals, as there are no brackets at the end to bother with, but the loose ends at the bulkheads have a rather weird appearance until the bulkhead liners are fitted and these ends gathered up. When fitted, however, very little ribbanding is required, which again is a saving, so that the whole of the work in the area of the oil tanks is a simple straightforward job.

The construction of the ends of the vessel also proves to be much more easy and cleaner work, but temporary measures may have to be taken to fasten some of the longitudinals in place towards the ends until the shell plating is fitted, so that really right from first to last in the new type of construction every compartment is more accessible and naturally more cheaply constructed, as all the costly work has been removed.

In the vessel built by my firm, there is a very slight increase in the weight of steel, but this is of very little account when the simplicity and rapidity of construction are taken fully into consideration.

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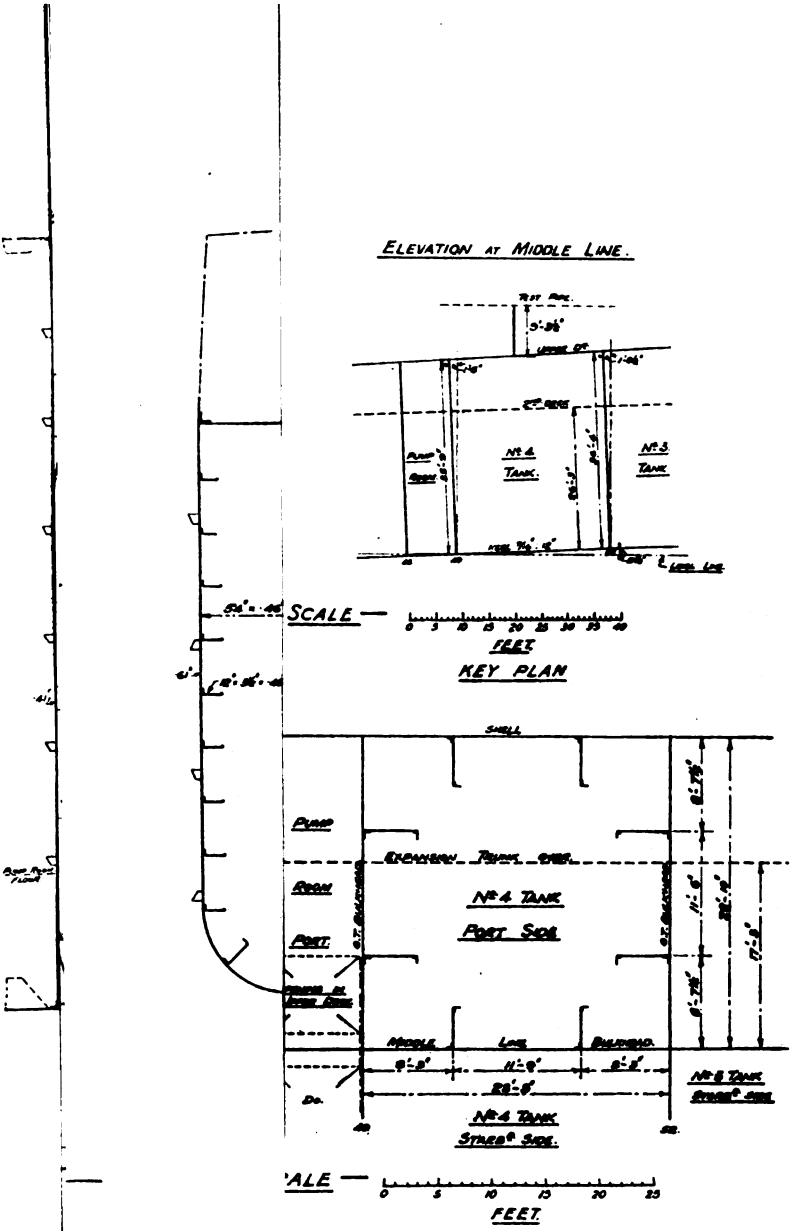

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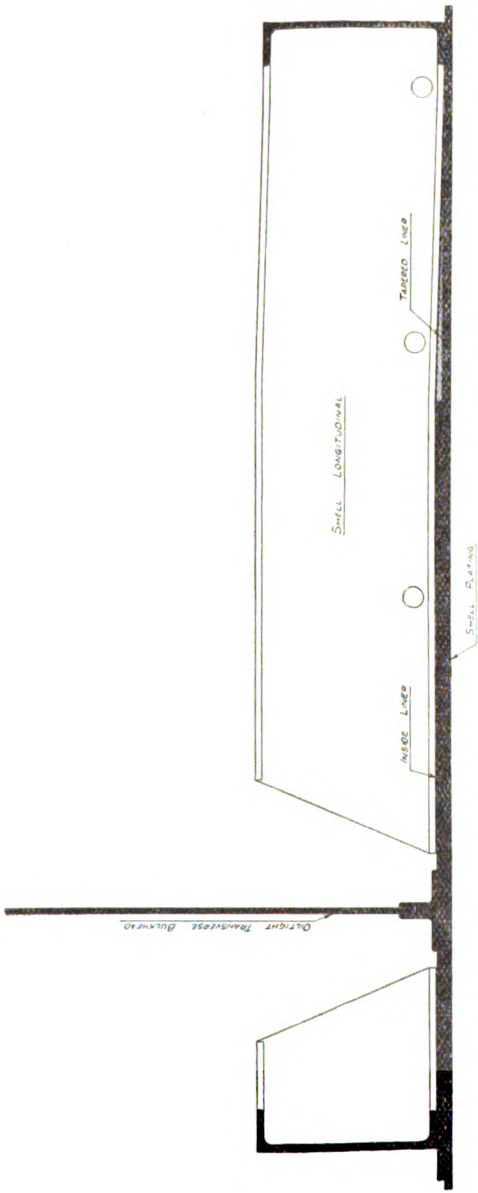

Fig. 15.—Method of Setting 17-inch Channel Longitudinals in way of Inside Shell Liners (Bracketless System).

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Mr. Thomas S. Simpson.

Fig. 16 illustrates a tank test carried out by my firm under the supervision of Sir Westcott Abell and Sir Joseph Isherwood, from which it will be observed that the deflections are hardly worth speaking about, and answer for themselves. Measurements were taken with the tank empty, the tank full, the tank under pressure, and after the tank had been run off. The greatest deflections of the structure are given, so that the diagrams are sufficient proof that the tanks are of more rigid construction than corresponding tanks in the bracketed ship, and prove the enormous advantages of the bracketless system.

Mr. A. J. Campbell (President): Many years ago Sir Joseph Isherwood gave some original thought to the methods adopted in the construction of ships, and introduced what was known as the fore-and-aft system of framing. Since then a great number of ships have been built on that principle, many being tankers. I am convinced that the bracketless system now brought forward by Sir Joseph is a marked improvement in connection with the construction of tank steamers. The practical points of most importance seem to be, firstly, the considerable reduction in the number of parts, plates, and small pieces, which have to be handled; secondly, that by the removal of the brackets, caulking is very considerably reduced; and thirdly, that a large amount of the most difficult riveting is avoided which otherwise would be a source of trouble.

Mr. C. R. H. Bonn (Associate Member): Obviously the greatest merit of Sir Joseph's new system of longitudinal framing is that the longitudinal members take up the bending-moment by flexure, and consequently the rivets attaching them to the bulkheads are merely under shear. It thus bears a strong resemblance to the pin-jointed truss girder. I think engineers engaged on structural steel work are too apt to forget, probably because the flexures in steel work are so small, that materials can only take up stresses through deformation.

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Mr. C. R. H. Bonn.

Rigid connections too often prevent the necessary deformation, and consequently members thus connected are not used to the best advantage, the stresses which they should theoretically bear being transferred elsewhere, to the detriment of the structure. I have often noticed the tendency of brackets to open up at the toe, and I put it down to the fact that the stress in the outermost rivet is enormous compared with that in the innermost; in fact, if allowance is made for the usual imperfections of riveting, the total load is apt to come on the outermost rivet, and practically no load is taken by the inner rivets, which, in the case of bulkhead bracketing, merely ensure watertightness. Is it any wonder then that brackets open up?

I cannot recollect having seen a method described for calculating the opening stresses in bracket rivets, but as I had at one time to design some columns, free at the top and bracketed to solid foundations to resist laterally imposed forces, I applied the bending-moment theory

$$WL = f\frac{I}{y},$$

where W = The lateral force,
L = Effective length of column,
f = Working stress,
I = Moment of inertia of rivets, and
y = The distance to the outermost of the equally disposed rivets.

As the columns are still standing up, I think I must have guessed pretty well; but I am sure there must be many besides myself who would be interested to know just how the stresses in bracket rivets are distributed.

I take it that the longitudinal members in the new Isherwood system are rigidly attached to the transoms, and that the flexibility of the transoms is such that those rigid attachments do not interfere adversely with the flexing of the longitudinal. This is a point which might be made clear.

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Mr. C. R. H. Bonn.

This paper is another example of the very great value of mathematical investigation. True, the results of such investigations are approximations, but if the problems are properly stated and the solutions correctly worked out, they are very real approximations, and the deviations from actual results will be proportionate in each case. There is no justification in the criticism that the results so obtained cannot possibly be the actual results. The development of both the original and the new Isherwood systems conclusively proves that such methods enable great advances to be made which could otherwise not be attained, because of the great first cost involved in obtaining actual experimental results.

Prof. Percy A. Hillhouse, D.Sc. (Vice-President): In connection with the subject of brackets, it might be interesting to mention something which I saw in an American destroyer during the war. She had come into Liverpool with a good portion of her stern missing, it having been blown off by one of her own depth charges. The bulkheads, however, had held, and she was able to make port. While she was undergoing repairs, I got permission to go aboard and have a look around. I noticed with great surprise that the longitudinals on the bottom, where they met the bulkheads, were not bracketed, but were simply connected by angle bars on either side; the whole strength of each longitudinal was reduced to the double sheer of three rivets. That is an example of the American habit of taking chances. In our ordinary methods of construction, it would have been considered necessary to fit brackets on each side of the bulkhead and largely increase the number of rivets, but they had simply cut the longitudinal, put on double lugs with about three rivets on each side, and let it go at that. The side rails were of phosphor bronze wire, presumably to obtain sufficient strength on the least possible weight, and yet alongside there were cast-iron post boxes.

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Mr. N. H. Burgess.

Mr. N. H. Burgess: Having had over 30 years' experience in the design and construction of oil tankers, it has been my privilege to become well acquainted with the various systems of tanker construction during that time. Although the general design of tankers has not materially changed during that period, the method of construction has completely changed during the last 15 years, principally due to the introduction of the Isherwood system of framing. Experience has shown that the Isherwood system is pre-eminently suited for this class of vessel, the reasons for which I will not deal with, as they are sufficiently well known.

I might mention that when a paper was read before the North-East Coast Institution of Engineers and Shipbuilders on the building of the first Isherwood tanker (S.S. "Paul Paix"), I stated at that meeting that this system of construction would prove to be a success, so that I can also claim to have spoken with the tongue of a true prophet. It is, therefore, of great interest to me to see Sir Joseph still striving for further improvements in the construction of tankers, and, personally, I have no doubt that the bracketless system will prove to be an ideal one, both from a shipbuilder's and a shipowner's point of view.

I am pleased to see that the main features of the Isherwood system have been retained. The transverses are what I would designate the primary members of the framing, and they are substantially the same as in the ordinary Isherwood system. If anything, I should say they have been made really stronger and stiffer. It is in the longitudinal frames, or what I would call the secondary framing, where Sir Joseph has made the departure from the ordinary Isherwood system, and, from a theoretical point of view, I see no reason why the new arrangement should not prove to be efficient. From a shipbuilder's standpoint, the omission of 5,500 pieces to handle (brackets and their connecting angles) in a 430-foot tanker is a tremendous step in the simplification of the framing of a tanker.

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Mr. N. H. Burgess.

I would like to suggest one alteration, and it is this. I am of the opinion that the liners or doublings on the ship's side would be more useful if they were transferred to the upper deck, thus providing for a liner or doubling on every strake of plating in way of the transverse bulkheads instead of on alternate strakes, the length of these doublings on alternate strakes being made slightly greater, as is done in the case of the doublings on the bottom of the vessels now building.

I have had the privilege of seeing the bulkheads and ship's side in a midship tank under pressure in the 10,800-ton tanker now building at Messrs. Palmer's shipyard, and was surprised to see how small was the deflection when compared with that which I observed in a transversely-framed ship of about the same size built about 20 years ago. The deflection in the bracketless ship was only about $\frac{1}{4}$ inch as compared with $\frac{5}{8}$ to $\frac{3}{4}$ inch in the transversely-framed tanker. I also noted that the actual deflection in the bracketless ship was about twice the theoretical deflection given on the diagrams in the paper. This agrees very closely with a similar comparison that I had the opportunity of making in the case of one of the earliest Isherwood tankers.

A point in connection with this new construction which the authors have evidently not considered worth mentioning is the consequent reduction in register tonnage due to the deeper longitudinals. I find the reduction amounts to at least one per cent., which reduction, I think, is certainly worth having in these days of strict economy.

In conclusion, I would like to say that our knowledge of naval architecture regarding the steel construction of ships has not always progressed on scientific lines. The structural arrangements of the old wooden ships seem to be too deeply rooted in our minds, and it is only within the last 15 or 20 years that naval architects, such as Sir Joseph, have taken courage and boldly departed from accepted methods of ship construction, and quite rightly so if thereby improvements

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Mr. N. H. Burgess.

and simplification leading to all-round economy is the result. With our greatly increased knowledge (partly derived from experiment) of the properties of mild steel and its behaviour when assembled and connected together in the various ways common to shipbuilding and structural engineering, there should be no doubt whatever about this new construction being efficient, especially after the careful investigations made by the authors, together with the approval of the classification societies.

Dr. G. Webster (Member): Just as the introduction of the Isherwood system of construction in 1907 revolutionised oil-ship design, so will the bracketless system, if successful, revolutionise not only oil-ship construction but probably that of the transverse cargo ship as well. In many problems in ship design it is impossible to calculate exactly the stresses which are borne by the various component parts of the structure, and we often have to depend to a large extent on practical experience to guide us. In the present proposal the amount of practical experience which we have is limited, but if time shows that the bracketless ship is as sound a proposition as the original Isherwood ship has proved to be, I think the shipbuilding community will owe a great debt of gratitude to Sir Joseph Isherwood and his son.

The function of the brackets appears to be twofold:—Firstly, they give a certain amount of fixity to the end of the longitudinals, and, secondly, they help to tie up the longitudinal material, and thus, to some extent, bring the longitudinals into the longitudinal strength of the ship as a whole. The authors confine their attention principally to the former of these two features, and produce results of elaborate calculations to demonstrate their views, but they make no attempt to estimate the effect of brackets on the longitudinal strength of the ship, which appears to be more important than any question of fixity of the ends of the longitudinals.

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Dr. G. Webster.

The results of the Bulkhead Committee's tests on the experimental tank at Messrs. Swan, Hunter & Wigham Richardson's, at Wallsend, showed clearly that the amount of fixity obtained by brackets at the end of stiffeners is very small, and from this point of view, I think the authors are on quite safe ground in leaving out the brackets. To some extent evidence can be produced from past experience to support the omission of brackets. Cases have been known in which the constant recurrence of slack and leaking rivets has been stopped by the removal of a bracket.

Shell doublings are introduced to compensate for the omission of the brackets in the longitudinal strength, but if experience shows that by this omission no unforeseen trouble arises, I think it is not improbable that it may be found eventually that the doublings can be reduced or perhaps omitted.

Sir Joseph W. Isherwood and Mr. Isherwood: We are indeed complimented that the discussion on the paper should have been led by Mr. J. Foster King, and particularly so as he is not averse to voicing his opinions frankly and fully and generally giving effect to them. We think it safe to say that Mr. King has been the leader in the great departures that have been made in ship construction since the introduction of the Isherwood system in 1907. Long before that date, and before one of the authors of the paper under consideration was born, Mr. King, on behalf of the British Corporation, had the courage to approve what was considered a great departure in ship construction, inasmuch as that Society, in 1893, co-operated in the building of a single-decked ship some 26 feet deep without a tier of hold beams. Up to that time the very thought of exceeding a depth of 24 feet without a tier of hold beams was heresy. Since that date, however, some hundreds of single-decked ships have been built of much greater depth than 26 feet, and it is unquestionable that they have given general satisfaction.

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Sir Joseph W. Isherwood, Bt., and Mr. William Isherwood.

It is, therefore, very gratifying to hear of Mr. King's approval of the elimination of brackets in what is now designated the "Bracketless System," and his approval strengthens the confidence we feel in this construction, and especially so as Mr. King gave his general approval of the Isherwood system some 18 years ago on the occasion when a paper describing it was read before the Institution of Naval Architects in London, and whilst the first Isherwood ship was under construction.

Mr. King comments on our comprehensive theoretical work which has been applied to the solution of the problem of placing the webs, frames, etc., and says he would probably have contented himself with the adoption of a simple formula. We might say, however, that in the conception of the new system such a rough and ready formula was adopted, but that did not satisfy us to any extent in determining what the spacing of the deep transverses should be, nor were we satisfied as to how much extra work was thrown on the transverses, on account of a maximum stress at the ends of the longitudinals when not bracketed at the bulkheads. We, therefore, commenced a more elaborate investigation, which subsequently led to others, and it is our opinion that these investigations have been of extreme benefit in coming to a decision. It might be mentioned that Mr. King's $\frac{wl^2}{16}$ and $\frac{wl^2}{12}$ would give a spacing ratio of 10 to $8\frac{1}{2}$ instead of 10 to $7\frac{1}{2}$ as suggested, as the bending-moment varies as the square of the length of the span.

Theoretical men of eminence have varying ideas as to what the spacing of transverses should be, and these range between 9—10—9, 8—10—8, and 7—10—7. Obviously steel weight could be saved if we were certain that the 9—10—9 ratio would be satisfactory, as naturally we did not desire to increase the steel weight more than was necessary, but the investigations which we have submitted satisfactorily prove

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that the 7—10—7 ratio would lead to a more efficient result than the 9—10—9 ratio.

It is true that there has always been a difference of opinion between Mr. King and Sir Joseph with regard to the longitudinal value of the materials which are devised to support the component parts of the main girder to enable it to withstand longitudinal stresses. Mr. King is of opinion that the supporting framework, no matter how disposed, should be considered on its own merits in relation to its own work and not as part of the shell. On the other hand, we hold the view that as the longitudinal materials are firmly riveted to the shell plating and deck plating, they become integral parts of the plating, and we cannot see how the two parts can be disassociated in our considerations, that is, as to whether the shell plating does certain work without the assistance of the longitudinals other than to stiffen the plating.

There has been a good deal of divergence of opinion in this respect, and it has been argued that the longitudinal stiffening should not be taken into consideration as resisting longitudinal stresses, because it has other work to do, such as to support the plating against local stresses due to water pressure, etc., and yet it appears to be overlooked that the shell plating has other work to perform than resist longitudinal stresses; it has to perform the work of adding to the frame strength, and yet all agree that the whole of the plating should be taken into account in the calculations for resisting longitudinal stresses.

The arguments appear to us to be illogical, but the proof of the pudding is in the eating, as has been shown by, what we might be pardoned for saying, the remarkable success of the Isherwood system. This especially applies to oil-tank vessels, in which the damage sustained through longitudinal stresses in the old transverse system has been entirely overcome, even in ships of double the deadweight carrying capacity to those built prior to the introduction of the system.

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Sir Joseph W. Isherwood, Bt., and Mr. William Isherwood.

Mr. Simpson has been good enough to supply deflection measurements, taken in an actual tank test, which will undoubtedly more than satisfy Mr. King that the deflections are very substantially less than those given by his standard. It may be that we have erred on the safe side, but by keeping the deflections so low we have in all probability obviated damage resulting at the ends of unbracketed stiffeners, such as Mr. King states might be possible through alternating stresses.

We thank Mr. King for his contribution, and consider that it has brought to notice many important points.

We appreciate the meaning of Mr. Thomas' remarks, but he will no doubt agree that a beam fixed at certain points is stronger than if merely supported at these points. As Mr. Thomas will no doubt appreciate, the term "fixity" in ship construction is only used in a comparative sense. We would, however, draw Mr. Thomas' attention to the fact (as mentioned in the paper) that we have not lost sight of the experience gained in the construction of some hundreds of ships, and we took advantage of Clapeyron's theorem to enable us to make comparisons with the known strength of particular parts.

If Mr. Thomas will refer to the second diagram, he will observe that with the 8—10—8 spacing of transverses the bending-moments are substantially $\frac{wl_1^2}{8}$, $\frac{wl_2^2}{12}$, and $\frac{wl_1^2}{8}$, Between this and the 7—10—7 ratio will be found Mr. King's suggestion of the 7½—10 ratio, which, as a matter of fact, is adopted for the transverse bulkhead webs spacing in the vessel now at sea.

We agree with Mr. Thomas that there is some contra flexure away from the transverse, but reference to the diagrams shows this to be less with the 7—10—7 ratio than with the equal spacing. In the light of experience, these considerations have justified us in the conclusion that we have adopted the

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Sir Joseph W. Isherwood, Bt., and Mr. William Isherwood.

correct ratio, and that Clapeyron's theorem has been of benefit in confirming our conclusions.

Mr. Thomas states that brackets have been dispensed with in the broad stringers at the bulkhead connection, but this is not an analogous condition, as the stringers were still rigidly attached to the bulkheads, although probably by other means than by brackets. It may, however, be mentioned that we have dispensed with brackets at the attachments of the ends of the deep transverses, as explained to Mr. King while he was making his remarks.

We do not quite follow Mr. Thomas' remarks in his closing statement, nor can we see the comparison of turning a thing round through an angle of 90 degrees, but it certainly cannot be made to show that the bottom of an ordinary vertically stiffened bulkhead is stronger than an Isherwood bulkhead owing to the absence in the former of the very deep webs fitted in the latter.

We are gratified to have the compliments and the approval of the system by a gentleman of Mr. Anderson's ability and experience. We were somewhat at a loss to know what figure to use for the modulus of elasticity. That given, namely, 10,000, was derived from some Admiralty experiments on light-class work, and it is possible that it will be found to be too high for ordinary mercantile work. It should, however, be borne in mind that the deflections are only made use of in a comparative sense, so that any discrepancy in the use of this figure will not be material. We shall, however, as a result of the tank tests made by Mr. Simpson, be able to arrive at a constant which will, we trust, be of very great value in making future deflection calculations for ordinary oiltight merchant work.

We note Mr. Anderson's suggested distribution of transverses of 6—12—6 instead of 7—10—7. The general opinion, however, of other experts with whom we have discussed the spacing ratio is more in favour of going to the

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8—10—8 ratio, for the reason that we arrive at the bending-moment of $\frac{wl_2^2}{12}$ for the middle span, *i.e.*, for a beam fixed at both ends, and $\frac{wl_1^2}{8}$ for the end spans, corresponding to a beam supported at both ends. So it is felt that we have kept well on the safe side by adopting the 7—10—7 ratio when for the unknown part, namely, the end span, where the bending-moment is $\frac{wl_1^2}{6\frac{1}{2}}$, it is generally admitted that our end spans are of beams with something better than support at each end. We feel that the load on the ends of the longitudinals in way of the bulkheads is a safe one with the ratio of 7—10—7 adopted.

We are much interested in Mr. Riddlesworth's comments, and wish to thank him for his contribution. With respect to his desire for elucidation in regard to the difference between points of support and fixity, as Mr. Riddlesworth will readily agree, absolute rigidity cannot be secured in the fastenings of the component parts of such a structure as a ship, and in many respects the same remarks apply in regard to the component parts of a bridge.

Now the deep transverse frames in an Isherwood ship, which are firmly riveted to the shell plating, are treated for comparative purposes as points of rigidity for the fixing of the longitudinals, although we do not argue for a moment that they are absolutely so, nor do we argue that where the longitudinal passes through the transverse and is connected to it by lugs, or otherwise, that the attachment at the point of intersection can be regarded as a fixed point. But in view of the fact that the longitudinal, as well as the transverse, are connected to the shell plating, we have for all practical purposes regarded this as a point of fixity, and experience in the construction of some hundreds of ships has demonstrated that this method of comparison with known similar structures is a reliable one.

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It is well recognised that the riveting attaching a flat plate to a girder or beam, such as a longitudinal, if efficient, very substantially increases the modulus of the longitudinal, inasmuch as the flange of the beam is in substance considerably increased.

The deflection of the deep transverses has been investigated, as will be seen by reference to diagram JB. It will be noticed that the deflection is very small indeed, even though the constant of 10,000 might require modification. This has always been borne in mind.

We think the tank-testing experiments carried out by Mr. Simpson fully answer Mr. Napier's question, and the deflection lines shown and obtained from measurements, at the suggestion of Sir Westcott Abell, at intervals of six inches, indicate that we are apparently quite safe at the part to which Mr. Napier refers.

The same reply might be made to Mr. Irvine, and the tests show that there is no bulging of the bulkhead plating between the ends of the stiffeners and the toes of the bulkhead bars.

We do not know whether to take Dr. Hillhouse's remarks seriously or otherwise. He probably means them to be taken otherwise. We are strongly of the view that the longitudinals do contribute to the longitudinal strength of the ship, and agree with him that the so-called "gymnastic feat" of distributing the stress lines will be watched with great interest.

The contribution of Prof. Abell and Mr. Gebbie is of great value, and we welcome it as such. A great deal of thought has been devoted to the snaping of the ends of the longitudinals where they are unconnected to the bulkheads by brackets. Dr. Robb's despised point of continuity of strength was, however, one consideration, and it was decided to maintain the full sectional area of the longitudinals in the vicinity of the doublings. As will be seen, the shearing stresses on the rivets connecting the longitudinals to the plating in the vicinity of the bulkheads have been carefully considered.

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However, a greater length of snaping at the ends of the longitudinals might be given effect to than has already been done, but this is probably an unnecessary refinement, and as such might not outweigh the practical advantages of the arrangement decided upon in the vessel already built.

It is possible that experience may show the necessity of welding across the flange of the stiffener to the shell plating, or some such device. As a matter of fact, we contemplated, in the early stages of the design, the fitting of short back bars to the plating at the ends of the longitudinals, but our investigations led to the conclusion that these were unnecessary, and probably undesirable.

It is unfortunate that Dr. Robb commences his criticism in such a way as to neglect practical experience, otherwise he would not dub as unsound reasoning the combined practical and theoretical experience of many years, in which theory has, as far as possible, been adapted to practice. I venture to suggest it will be a long time before the elements will accommodate themselves to conform to Dr. Robb's theoretical expressions of opinion that have no foundation in fact.

It might be thought from the reading of Dr. Robb's contribution that the shell plating of a ship has no other duty to perform than to provide the necessary longitudinal strength of the ship, and if the shell plating contains more material than is necessary to provide the requisite longitudinal and transverse strength, and, to use his own words, "assuming that its extent is calculable," how much of such material is not being used to the best advantage? Dr. Robb's conclusions, based on the arguments of Mr. William John, bear no analogy to the case under consideration, and Mr. John's arguments do not justify or indicate that longitudinal framing is only a matter of convenience because of the close spacing of the transverses.

We would again ask Dr. Robb if the elements will consider his theory—theory unsupported by an atom of experience

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other than the chanting of the Grecian chorus quoted by him, which, we must remark, is of little interest to us in the consideration of our subject.

It is somewhat remarkable that Dr. Robb raises what he calls a minor constructional point, in regard to the deflection of the side longitudinals during erection being so great as to introduce difficulties when the time comes for the fitting of the shell plates. This has been demonstrated by experience in actual construction to be a point without substance.

We are much interested in Mr. Crawford's contribution, inasmuch as he co-operated very helpfully in the construction of the first Isherwood ship built on the Clyde, namely, the "Craster Hall," built by Messrs. William Hamilton & Co., Port-Glasgow, for the Hall Line (Messrs. Chas. Dunn & Co., Liverpool). This was the second general cargo vessel, the first being the "Gascony," built by the late firm of Messrs. R. Craggs & Sons, Ltd., for Messrs. David McIver & Co., Liverpool.

We think Mr. Crawford will agree, after examination of the results of the tests produced by Mr. Simpson, that they are from a comparative sense borne out by practice, and we are able to say that the tank-testing operations were never carried out more smoothly in any oil-tank vessel previously constructed.

We thank Mr. Crawford for his intimation that Clapeyron's theorem is quite frequently used in caisson and floating-deck design. We have not had any practical experience with this type of floating structure, but Mr. Crawford's advice is comforting in showing that the application of this theorem is not so dangerous as one might gather from Mr. Thomas' implications.

Mr. McGovern's anticipations have been fully realised, and the contribution from Mr. Simpson should be of value to him. In the erection of the ship now in service, it was an exceedingly simple matter to secure the ends of the longitudinals.

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Sir Joseph W. Isherwood, Bt., and Mr. William Isherwood.

We are greatly indebted to Mr. Simpson for the useful and instructive information he has been good enough to supply. Mr. Simpson can speak with authority, inasmuch as the first vessel of the new type was built under his direction and supervision, and we are grateful to him for his valuable co-operation in the settlement of the multitudinous details that obviously arise for discussion when any great departure from established practice is made.

Dr. Webster's contribution is very interesting. We agree that an important point in the consideration of a bracketless ship is the elimination of fixity, or comparative fixity, at the ends of the longitudinals, which feature Dr. Webster states we have fully dealt with.

We are pleased to note that Dr. Webster agrees with us, contrary to the views of Mr. King and others, that the longitudinals do enter into the longitudinal strength of the ship, and we cannot conceive otherwise. Our opinion is that the doublings fully maintain the continuity of the longitudinals, and we venture to say that further elaborate tests not yet detailed or published confirm our opinion and support Dr. Webster's and our views as to the value of the longitudinals in contributing to the longitudinal strength and stiffness of the ship as a whole.

We quite agree with Mr. Burgess that it was essential to have the strength of the transverses (the primary members) beyond question. They are, of course, of greater scantling than in the ordinary Isherwood system, due to the additional load put upon them by the elimination of the fixed points of bulkhead connection.

With regard to the redistribution of the doublings, we consider this point well raised and worthy of serious consideration. We, however, hold the view that the side doublings are advisable to take care of any possible alternating stresses at the ends of the longitudinals due to water pressures.

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Sir Joseph W. Isherwood, Bt., and Mr. William Isherwood.

The actual deflection results were certainly very satisfactory, and, further, go to show that the calculations we have made, whilst probably on the safe side, give us more or less anticipated results, subject, of course, to the correction of the assumed modulus of elasticity for commercial merchant work; but from the elaborate experiments that have been made in this vessel, we feel we shall now be able to arrive at a more correct modulus for this class of work.

The reduction in the register tonnage was certainly realised.

It has always been our opinion that comparative theoretical means can be applied to a ship even though it may be complicated by the varying conditions, and it is essential to use such means to secure the strongest and most economical ship.

Mr. Campbell's remarks are very pleasing, and it is very gratifying to receive them from such an eminent and practical man. We can assure him that the points he raises were all borne out in fact in the first vessel constructed.

We are in agreement with Mr. Bonn regarding the great difficulty of estimating true stresses when dealing with such a complicated and elastic structure as a ship, and are interested to learn of his observation regarding the behaviour of brackets.

His method of calculating the stresses on the rivets in the base connection of a column is practically the same as we adopt in finding the approximate stress on the outermost rivet in a bracket connection, namely, by taking the rivets in one arm of the bracket and multiplying the area of each rivet by the square of the distance from the other arm, and dividing the sum so obtained by the distance to the outermost rivet. This gives approximately the I/y of the rivet connection, and, knowing the bending-moment, it is possible to find the stress on the outermost rivet due to bending, to which, of course, must be added the additional small stress due to shear forces. This method has been put into practice in some 15,000 Isherwood ships, ranging from small barges to Atlantic liners 535

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feet long, and to oil tankers up to 20,000 tons deadweight carrying capacity, with satisfactory results.

The reason, however, for the elimination of the brackets is, firstly, reduced labour cost of construction; secondly, speed of construction; thirdly, reduction in cost of damage repairs; fourthly, greater ease of clearing in oil-tank vessels; and fifthly, oiltightness of bulkheads.

As mentioned in reply to Mr. Burgess, we are absolutely in agreement that mathematical investigation of ships' structures is essential if great advances are to be made in ship construction.

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SOME PROBLEMS RELATING TO THE MANUFACTURE AND USE OF RUBBER TYRES.

By A. Healey, B.Sc.

13th April, 1926.

Object of the Paper.

The rubber industry is still in its infancy, and is, therefore, in a state of rapid development. It is not surprising, then, that the general public has but a rudimentary idea of the nature of rubber and of the manufacturing processes employed. Of the technical and scientific problems involved, nothing is known except by those directly interested in manufacture.

It is hoped that the present paper will prove interesting to engineers and to tyre users, by giving some account of the problems that have been solved and of those yet to be solved, of the present commercial applications of rubber, and of the future possibilities. The paper is not intended to be a handbook for those interested in rubber manufacture, nor a technological treatise, nor a history, but simply to create interest, and perhaps stir the imagination of the reader.

Scope of the Paper.

Although limited to the tyre industry, there is no need to chafe under the limitation. Not only is the bulk of the rubber produced used in tyres, but also the mechanical and physical problems involved in tyre manufacture have been almost entirely responsible for the advance in knowledge of rubber. Conveniently a beginning may be made by asking,

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Why are Tyres Made from Rubber?

The function of a tyre is to bend rather than to break. The impacts which a vehicle wheel receive are inversely proportional to the bending of the tyre. In order to make rapid transit possible the degree of bending must be large, and in the present state of development of road-making and of vehicle designing it is found necessary to make provision for a tyre to bend, or deflect, up to a maximum of about three inches.

It is theoretically possible to construct a mechanical tyre of metal, or other solid, so as to give this deflection of three inches, but it has hitherto been found impracticable. In some cases the tyre would fail from fatigue, occasioned by repeated bending; in others the weight would be too great. Rubber has the advantage of being tough, light in weight, easily bent, and able to resist fatigue to an extraordinary degree. For example, the rubber in a solid tyre which accomplishes 100,000 miles has been alternately bent and released about 50,000,000 times, and is found to be little changed in physical properties even then. I know of no case where the rubber itself in a tyre has failed as a result of fatigue. This is not to say that tyres never fail by fatigue, but that when they do so the failure is at a junction between rubber and cotton (or some other solid material), or else in the cotton itself.

Carrying the inquiry a step further, the question may be asked—

What *is* Rubber?

What is the secret of the extraordinary physical properties of rubber? Actually the rubber in tyres (and in almost all other rubber articles) has undergone two distinct transformations, both of which were discovered accidentally. The rubber tree supplies a watery fluid, "latex," which is a suspension in water of minute rubber globules. These globules are not simply colloidal particles, but have a definite structure which

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is capable of microscopic examination. There is roughly 70 per cent. of water in the rubber latex.

If the water be evaporated so as to concentrate the latex, coagulation of the rubber particles occurs. This is the first transformation. Coagulation may be induced by adding acid to the latex, or by centrifuging. The coagulated particles cohere very strongly, and cannot by any known means be separated without being partially destroyed. The substance produced by coagulation is the solid known as "raw rubber," whose physical state can be most truly and visually described as "gristly." It finds a commercial use in shoe soles (crêpe), but is unsuitable for tyres, for the reason that it loses its toughness and solidity when warmed only moderately (to about 60 degrees C.), becomes objectionably sticky, and flows easily under pressure.

The second transformation is called "vulcanisation." The rubber attains a more rigid and a more stable structure, practically unchanged by temperature variations, and consequently finds much greater commercial application. When once vulcanisation has occurred, the rubber cannot be changed back to its original state. The transformation, like the first, is irreversible. For this reason, vulcanised rubber scrap is of comparatively little value, and the so-called "reclaiming" processes consist merely in partially burning the scrap and soaking it in oil to make it plastic. The "reclaimed" rubber is thus "half-destroyed" rubber.

Vulcanisation is usually induced by heating a mixture of rubber and sulphur. It is accompanied by a minor chemical action, but the degree of vulcanisation is not dependent on the extent of chemical action. The change in physical properties from "raw" to "vulcanised" is a continuous one, for all practical purposes, and can best be visualised as follows:— Raw rubber consists of a very viscous fluid, containing a tenuous, but exceedingly tough, fibrous structure. Vulcanised rubber consists of the same two fluid and fibrous parts, but

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the latter is by far the more important, being very thick and massive, while the fluid portion is attenuated. When raw rubber is heated, the fluid becomes much less viscous, and the material has then very little solidity, while the heating of vulcanised rubber has little effect on the solidity.

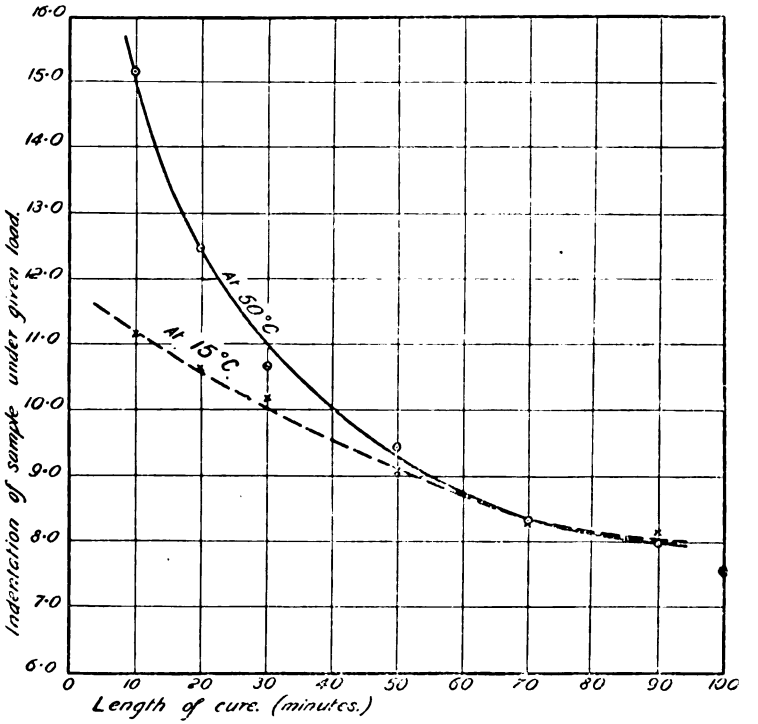

Fig. 1.

Fig. 1 shows the results obtained in tests at 15 degrees C. and 50 degrees C. on the hardness of a number of samples of the same mixing, vulcanised for different lengths of time. The convergence of the two curves shows the decreasing effect that temperature has on the hardness of the mixing as the time of cure increases. In this particular case the mixing was completely cured at 70 minutes.

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The Physical Properties of Vulcanised Rubber.

Although the two natural transformations of coagulation and vulcanisation must occur before a vulcanised rubber solid may be obtained, there are several means open for modifying the extent and power of their action. For example, the same *kind* of transformation will produce a soft flexible substance as used for tobacco pouches, or a hard substance as used for ebonite. The difference is one of degree only.

It will be realised that the art of the tyre technologist lies in making full use of all the means at his disposal for controlling the physical properties of vulcanised rubber. Consequently, he must attack the tyre problem from two points: firstly, to find what physical properties are needed in a tyre; secondly, to find what physical properties may be obtained from rubber. A little knowledge of this subject is necessary before an intelligent interest can be taken in the design, construction, and even the use of tyres.

FACTORS WHICH INFLUENCE THE PHYSICAL PROPERTIES.

Degree of Vulcanisation.

The vulcanisation, as stated above, is a continuous process, and in tyre manufacture one of the fundamental problems is to determine at what stage the process shall cease. For any particular purpose there is a best stage, known to rubber pedants as the "optimum." The rubber used for simultaneously joining and separating the plies of a motor car tyre will fail if the vulcanisation is carried too far, or not far enough. In the first case, the rubber is weakened when the tyre becomes hot; while in the second case, the rubber is weak even when cold. In both cases, the plies of the tyre will loosen and lead to early failure.

Acceleration of Vulcanisation.

It was observed that some raw rubbers arrived at the best stage of vulcanisation (or "cure") in a shorter time than did

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others. Research on this point indicated the presence in some rubber samples of small quantities of foreign substances, which acted in the manner of catalysts, inducing a more rapid vulcanisation. This led to the discovery of artificial catalysts, known now as "accelerators of vulcanisation." These "accelerators" are extremely useful tools to the rubber technologist.

Compounding Ingredients.

Visitors to rubber factories who see the process of mixing rubber with various kinds of powders are inclined to think that this is a trick for saving money, and that the public are being defrauded. It is not suggested that this view is held seriously, but yet some kind of explanation is necessary.

In the first place, modern tyre mixings were developed at a time when rubber was cheaper than most of the compounding ingredients used, and economies could have been effected by using more rubber. Zinc oxide costs 3¾d. per lb., and is six times as heavy as rubber, volume for volume. It is not, therefore, economical to use zinc oxide in place of rubber until rubber is 20½d. per lb. Yet enormous quantities of this powder went into solid tyres when rubber was less than 12d. per lb. This is mentioned to illustrate the fact that the designing of rubber compounds is a technical problem, cost being a secondary consideration.

It might be thought that a mixture containing 80 per cent. of rubber and 20 per cent. of carbon black (by volume) would be physically the same as one containing 80 per cent. of rubber and 20 per cent. of magnesium carbonate, because the mixture in each case is a mechanical one simply, and the rubber can easily be separated from the powder by physical means. Yet the former mixing would be good for pneumatic tyre treads and quite hopeless for solid tyre treads, while the latter would be exactly opposite, making a good solid and a bad pneumatic tread. The reasons for this will be understood from the considerations that follow.

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Physical Properties.

Tensile Strength. Calculated on the cross-section of the test piece at break, the tensile strength of various types of mixings are roughly as follows:—

	Lbs. per square inch.	Stretch at Break. Per cent.
Pneumatic tyre tread -	3,000	650
Solid tyre tread - -	2,410	400
Motor tube - - -	1,990	850

Resistance to Abrasion. The value of rubber in this respect can be seen from the fact that a tyre on a heavy touring car will be worn less than 1 mm. for 1,000 miles, or for half-a-million revolutions.

Carbon black is generally considered to give to rubber the highest possible abrasion value, and that is why almost all tyre treads are black. Magnesium carbonate and zinc oxide are considerably inferior, but they have advantages in other respects.

Internal Friction. This property is capable of giving considerable trouble in cases where heat is rapidly generated and is unable to escape, as in solid tyres and racing tyres. Under ordinary conditions of tyre use, the internal friction is responsible for the conversion into heat of one quarter of the total energy used in bending the tyre.

Ageing. This characteristic requires careful attention, being influenced very largely by degree of vulcanisation, by the "accelerators" used, and by the amount of sulphur and compounding ingredients used. The perishing of rubber articles is well known to be a serious factor, and the long life of the modern tyre may be taken as the result of skilful design, supported by long experience. There are other properties of secondary importance which need not be dealt with here.

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Compounding Ingredients.

The principal ingredients used in tyre manufacture are given below, together with their chief characteristics.

1. *Carbon Black, or Gas Black.* At the moment, this "smoke" powder is used to a large extent in almost all pneumatic tyre treads, because it imparts both toughness and high resistance to abrasion. Unfortunately carbon black gives large internal friction, and it cannot be used to the same extent for solid tyres.

The conventional pneumatic tyre tread contains by volume about 73 per cent. of raw rubber, 20 per cent. of carbon black, the remaining volume consisting of vulcanising agents.

2. *Lamp Black.* This powder differs from carbon black in physical properties, although it is almost the same chemically. It is formed by burning oil with a limited supply of oxygen, and gas black is formed by burning the natural gases found in the U.S.A. The particles are probably larger in lamp than in gas black, but in each powder they are too small to be observed microscopically. Lamp black is not quite so good as its cousin in respect of resistance to abrasion, but it gives a much lower internal friction, and so finds considerable use in cases where it is important to avoid generation of heat.

3. *Zinc Oxide.* Although a very costly ingredient, zinc oxide has been, and still is, used extensively on account of its ability to impart toughness combined with small internal friction. It does not give a good wearing compound for tyre treads.

4. *Magnesium Carbonate.* This filler is used very largely by some makers of solid tyres, because of all the fillers it gives the lowest internal friction. However, the resistance to abrasion is small, and there are many practical difficulties in manufacture, one of these being the exceedingly dry nature of the raw mixing, making adhesion of the various parts somewhat weak.

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5. *Coarse Fillers, such as Barytes, Whiting.* These are hardly ever used in tyre manufacture, because they simply serve to dilute the rubber, and do not impart to it any good physical properties.

It will be realised that a rubber compound need not consist of rubber and one filler only. Usually two or more fillers are combined, and in many cases it is very advantageous from the service point of view.

I have illustrated the complexity of the problem of finding the most suitable rubber compound to use for any particular purpose, and come now to the problem of designing a tyre. If an attempt were made to treat this in a general way, including the relative merits of solid, cushion, pneumatic, and other tyres, the result would be, in this short paper, failure to arrive at any conclusion. It will be best to take the present-day tyres, and to show why they are made as they are.

The Pneumatic Tyre.

Tyres of the pneumatic principle are used for vehicles of all weights, from the bicycle to the commercial lorry, for aeroplanes, racing cars, etc. The factors which determine the suitability of a tyre to perform certain duties include:—

1. Abrasive wear of tread.
2. Fatigue of cotton foundation.
3. Liability to accidental damage.
4. First cost.
5. Comfort capacity.
6. Skidding.
7. Appearance.
8. Weight.
9. Power consumption.
10. Lateral stability.
11. Liability to develop high temperatures.

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Each of these factors, in turn, is dependent upon the constructional features of the tyre. For example—

1. Depends on (a) Shape of tread section.
   (b) Tread pattern.
   (c) Quality of materials.
   (d) Inflation pressure.
2. Depends on (a) Size of tyre section.
   (b) Number of plies.
   (c) Thickness of cord.
   (d) Inflation pressure.
   (e) Thickness of tread.
   (f) Quality of cotton.
   (g) Cord construction.
   (h) Tread shape and thickness.
   (i) Temperature developed.
   (j) Type of "insulating" rubbers used.

And so on.

Not only are there a large number of factors, but they are connected and cross-connected in a very complex way, as shown in the chart, Fig. 12. The factors 1, 2, 3 . . . are more or less important, according to the type of tyre considered.

The Bicycle Tyre. Factors 1 and 2 are the most important. There is no possibility of high temperatures being attained. For racing tyres, weight and power consumption are the vital factors.

The Small Car Tyre. 1 and 2 are again the most important.

The Giant Pneumatic Tyre. While 1 and 2 are very important, 9 cannot be overlooked, and steps must be taken to see that unduly high temperatures are not attained. This factor becomes important because of the great thickness of tyre materials, and of the large loads carried.

The Racing Car Tyre. 9 is the most important factor of all.

The Aeroplane Tyre. 8, 5, 3, 2 are the most important.

This brief summary is sufficient justification for referring to

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tyre designing as an art rather than as a science. There is, indeed, as much artistic effort required as in planning a house, and just as houses, intended for the same purpose, differ from each other according to the plans of their respective architects, so tyres differ according to the designs of different technologists. There is no definite "ideal" house, and cannot be one; there is not and cannot be an ideal tyre. A successful tyre depends not merely on scientific knowledge, processes, and experience, but also on creative imagination.

I will pass on now to consider a few isolated problems of interest to all people who have anything to do with cars, as well as to engineers in other spheres.

Abrasive Wear of Tread.

It is clear that the tread is worn away because the rubber is first pressed against a rough surface, and then dragged across it. The rate of wear depends on the amount of the pressure, on the distance of the slip or drag, and on the roughness of the road surface.

It will be realised that any particular part of the tread has a certain history during its period of contact with the ground. Both its road pressure and its slip are continually varying. It may happen that the pressure is low when the slip is high, resulting in very little wear. On the contrary, a high pressure and a high slip occurring together will produce rapid wear.

This general principle is sufficient to explain most of the phenomena of tread wear, but its application to any particular problem is very complex. In the first place, the two factors are not entirely independent, for an excessive pressure at any point tends to reduce the amount of slip at that point. This fact is of very great importance, as will be seen later. This precise amount of slip is difficult to determine, and will alter as the tread wears away, especially if the wear be uneven. The same comment applies also to the road pressure.

The difference in behaviour of front and rear tyres, often

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noticed, is due to the difference in the behaviour of the wheels. The more obvious differences between front and rear wheels are:—

1. The front wheels are liable to vibrate in the steering sense, and are known to do so, from observation of other cars and of the steering wheel itself. Even when no regular wobble occurs, the steering wheel is generally rather unsteady.
2. The front wheels are usually rolling only, while the rear tyres are usually rolling and transmitting power. This power transmission, being applied evenly over the whole surface of contact, tends to wear out the tread more rapidly, and to mask, in some degree, any unevenness of wear due to the inevitable slip of deformation.
3. The front wheels are not always set to run in perfect alignment, but are toed-in.
4. The front wheels are not always in a vertical plane, but are inclined outwards.

With these facts and principles in mind, it is not difficult to solve a problem that has confronted the tyre designers from time to time, and which suddenly became far more acute on the introduction of the balloon tyre. This is the problem of extraordinarily rapid and irregular wear of the treads of front tyres.

In some cases abnormally rapid general wear takes place, and in others a peculiar phenomenon occurs, and at more or less regular intervals round the tyre large lumps or knobs of rubber stand out apparently untouched, while the tread in between is completely worn down.

At first sight it would appear that the knobs of rubber should be rapidly worn off, but when we remember that the intensity of the pressure is great on the knob and small on the surrounding part, it is clear that the knob may not slip on this very account, and in consequence will not be worn. The effect is

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that a comparatively small irregularity will be cumulative, so long as the tyre is subjected to a pure rolling motion only. If, as in the case of a rear wheel, the whole tyre is compelled to slip under a driving load, the knobs will be worn more rapidly than the surrounding parts, and the wear will be even.

It is necessary to explain at this point why irregular wear is more liable to occur with low-pressure than with high-pressure tyres. The high-pressure tyre is not only inflated more, but is itself stiffer than the low-pressure tyre. Any outstanding knob of rubber is unable to grip the road and compel the surrounding parts of the tyre to adjust themselves. The ordinary and inevitable pattern slip is controlled by the stiff, hard casing, and a small knob of rubber cannot remain, for it is compelled to slip in spite of its high road pressure.

The conclusion to be drawn is that irregular wear is allowed to develop on a soft and flexible casing. It is interesting to observe the gradual development of the effects of heel and toe action, from a slight inclination of the surface of a stud to a well-defined smaller stud with edges all complete.

Rapid General Wear. In the case of wheels which are inclined to the vertical, there is, of course, a tendency for the wear to be more rapid on one side in all types of tyre. In soft balloon tyres, however, the effect is again cumulative. Where the tread is worn, the tyre becomes much more flexible, and the unworn part carries the bulk of the load. The unworn part, therefore, grips the road, and the worn part has to adjust itself as well as it can by slipping on the road surface. Thus the extra wear on one side becomes relatively greater as time goes on.

Non-Skid Effect. The coefficient of friction between rubber and almost any kind of dry road is very high, and may approach 0·8 on occasion. An ordinary tyre could hardly be made to slip on plate glass, for example. It is a common experience that there is never any difficulty in holding the road, except when the road is greasy or wet.

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The most important circumstances under which a tyre loses its grip of the road are:—

1. When the road surface is covered with mud of a certain type, so that the tyre rolls on a film of fluid, in much the same way that a metal bearing rolls on a film of oil.

2. On a very smooth road surface, a layer of water is sometimes sufficient to deprive a tyre of its grip. This usually occurs during a heavy rain, or when rain has just commenced to fall, and lies on the road in thick blobs. In the latter case the wheel tracks appear to be wetter than the rest of the road, because the blobs have been flattened out by the tyre. This phenomenon is due to the inability of the rain to wet the road, perhaps owing to a film of oily matter.

3. On some types of snow and ice.

Of these circumstances, 1 is the most common, while 2 is the most dangerous, being unexpected by the average driver from the general state of the road.

In spite of the comparative rarity of 2, it probably accounts for more accidents than 1, partly because it is unexpected, partly because it results in complete loss of control, and partly because it occurs only on good roads where the traffic is heavy. There have been several cases reported where a number of vehicles have been concerned in a general collision because of the peculiar condition of the road.

Laws Governing Tyre Grip to the Road.

Many engineers hold very tenaciously to the opinion that "the smaller the area of contact, the greater the resistance of the tyre to skid." The reason given is that the smaller the area of contact, the greater the average pressure between tyre and road, and consequently the better chance the tyre has of penetrating the mud. A little consideration will show this to be fallacious.

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The modern broken tread gives usually about 30 per cent. less area of contact than a plain tread, under the same conditions of tyre size, shape, inflation pressure, etc. In the balloon tyre this reduction is lost, and, in fact, the area of contact is even greater than that of the plain tyre which it would have replaced. Yet the balloon tyre is at least equal, in respect of road-gripping qualities, to the high-pressure tyre with a broken tread, in spite of the difference in contact area. The area of contact cannot, therefore, be regarded as a criterion of non-skid value, and, in fact, has very little bearing on the question.

If two flat surfaces are separated by a fluid film, the resistance to sliding is proportional to the viscosity of the fluid, to the speed of sliding, and to the "area of contact" so-called, and is inversely proportional to the thickness of the film. In other words, the sliding resistance is greater for a thinner film, a more viscous film, a larger area, and a higher speed.

The thickness of the film separating two surfaces may be reduced by pressure, acting for an interval of time. Theoretically the fluid can never be absolutely squeezed out, but in practice the surfaces are not perfectly smooth, and there comes a time when the film is sufficiently thin to allow the irregularities to make contact. If, for example, a road surface has minute hills and dales, contact can be made by a tyre even when a certain amount of fluid remains between the rubber and the road. This has an important bearing on the subject.

Any individual stud of a tyre is in contact with the ground for a small fraction of a second only. A speed of 40 miles per hour is equivalent to 60 feet per second, and even if a tyre had a surface of contact a foot long, a stud would be in contact only $\frac{1}{60}$th of a second. One reason for the good grip of a balloon tyre is its length of contact, resulting in an individual stud remaining in contact for a comparatively long time.

Consider a stud of definite area being pressed against a road surface covered with fluid for a certain time, say, $\frac{1}{30}$th of a second. The more viscous the fluid, the greater will be the

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thickness of film remaining between the stud and the road at the end of the time, and the less will be the resistance to sliding. On the other hand, the greater viscosity of the fluid tends to increase the resistance. There are thus two factors operating in the opposite direction.

It can be proved that the greater viscosity produces the greater sliding resistance. Applying this result to mud and water on a perfectly smooth surface, it means that, though a tyre will squeeze water into a much thinner film than it will mud, the viscosity of water is so small that it offers much less resistance to slipping than a thick film of mud.

The reason why a wet road is usually less dangerous than a muddy road is that the small irregularities of the road are large compared with the thickness of the water film, and small compared with the mud film. Our road tests prove that there is practically no difference between dry and wet tar macadam, as far as tyre grip is concerned.

A film of water $\frac{1}{2500}$ of an inch thick, remaining between the tyre and the road, would reduce the resistance to sliding from 500 lbs. to 5 lbs., and the result is a "floating" sensation, a very light touch of the brake causing a slip, and the car failing to respond to the steering wheel. This abnormal condition is removed when the wheels are locked.

When a film of fluid, of any kind, completely separates the tyre and the road, there is no grip in the ordinary sense of the word. A very small force will suffice to produce a slip, and the greater the force, the greater the speed of slipping.

This is illustrated in the case of a car travelling on a cambered road having granite setts, covered with greasy mud. The small force tending to pull the car down to the gutter is sufficient to produce a gradual slip which needs continual correction. At low speeds the tractive effort of the engine is small, and the fore-and-aft slip is so small that it is unnoticed.

The foregoing considerations apply only to the case of a rolling tyre, and its capacity to prevent a skid commencing.

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An entirely different problem arises when a wheel is slipping either forward or sideways at any high speed.

Racing Tyres.

The modern racing tyre is called upon to run at speeds up to 150 miles per hour, and its diameter is limited to about 37 inches. Any particular point of the tyre is compressed and released under these conditions, about 24 times per second.

At every compression and release a certain quantity of heat is generated, and there is only $\frac{1}{24}$th of a second before a further quantity is added to it. The temperature of the tyre thus rises rapidly, and soon heat is dissipated at the surface. When the temperature is so high that as much heat is dissipated as is generated, no further rise in temperature occurs. It is necessary to design the tyre in such a way that this equilibrium temperature is not high enough to burn any of the parts. Further, the enormous centrifugal forces must be allowed for.

On a tyre of 32 inches diameter, running at 150 miles per hour, the centrifugal force on any piece of tread is 1,100 times its weight, and at this speed the actual force tending to separate the tread amounts to about 156 lbs. per square inch. This leads to a change of shape of the tyre, which becomes elliptical in cross section, the major axis being radial to the wheel. Fig. 2 shows the change in sectional shape at 1,500 r.p.m. Since the running diameter of the driving wheels of a racing car must be very accurate as to size, the centrifugal action must be allowed for.

Balloon Tyres.

The balloon tyre is a good illustration of the need for considering a large number of factors at once. Why has there been an increase in tyre sizes since 1923? This can only be answered by calling to mind the more important considera-

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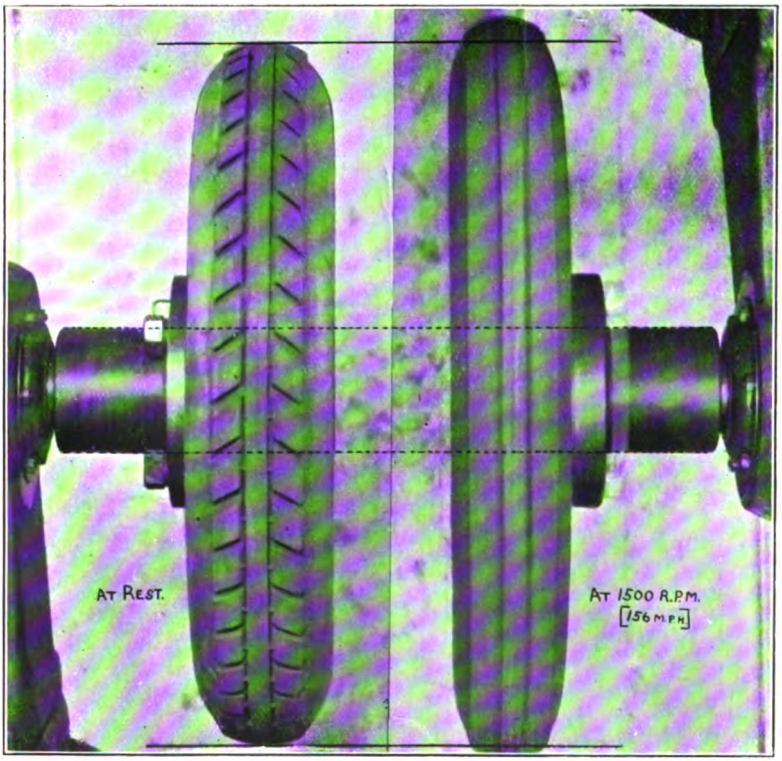

Fig. 2.

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tions determining the size of tyre to suit any particular car. These are:—

1. First cost.
2. Length of service, freedom from trouble.
3. Comfort to be derived.
4. Appearance.
5. General effect on the car's performance.
    (a) Stability.
    (b) Tractive resistance.
    (c) Steering.

Changes in the means of transport (both roads and vehicles), in public opinion, and in the economic situation, produce changes in the relative importance of these five factors. In 1913 nobody cared about anything but cost, and service (and very little about that). The remaining factors were never mentioned. Factor 4 had its effect about the year 1919, and led to the present-day smart appearance of tyres. In 1922 much attention was given to comfort, and some people thought that a tyre could not be made too large, because even very large tyres seemed more or less to satisfy the requirement of cost and service. The other factors were not adequately considered, and so very large tyres were proposed, made, and sold. These were called "balloon" tyres. It was soon found that the balloon tyres, as made originally, had an adverse effect on the performance of most cars—reducing acceleration and maximum speed; giving rise to objectionable vibrations; and impeding the steering action.

Accordingly sizes were reduced, until the balloon tyre became what it is to-day, no more than one size larger than the normal —a change advocated by leading tyre manufacturers ever since there were tyres at all. As an example, the case of cars with an axle load of about 20 cwts. may be quoted. The ordinary tyre was of nominal 4½ inches section, and actually measured 4·77 inches. The balloon tyre first recommended in America

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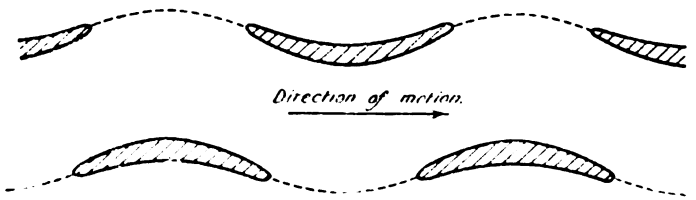
was 6·2 inches, and the size recommended to-day by the Dunlop firm is 5·25 inches. If the customer really desires comfort at the expense of other things, he is given a 6-inch tyre.

Front Wheel Wobble.

This phenomenon is usually associated with balloon tyres, and it is convenient to refer to it at this point. As the mechanical principles involved are interesting to engineers, no excuse is offered for making this little digression.

There are two main types of front wheel wobble. One of these occurs at speeds of about from 20 to 30 m.p.h., and is



Tracks made by front wheels during high speed wobble.

Fig. 3.

merely a steering oscillation usually arising from slackness in the steering mechanism. The other, which is by far the more important one, occurs at higher speeds—usually above 45 miles per hour. In this case the movement of the wheels from side to side is coupled with a violent oscillation of the front axle about a horizontal axis through its centre and perpendicular to the axle, causing the front wheels to leave the road alternately. The car is set in violent lateral vibration, and the whole thing is very uncomfortable and alarming to the driver, and still more alarming to a spectator, to whom the car appears to be entirely out of control. The tracks made by the front wheels in a bad case of wobble are shown in Fig. 3. These are drawn from actual measurements taken on the road.

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Briefly, the explanation of this phenomenon is as follows:—The front axle, supported between the chassis springs and the tyres, is free to vibrate in two ways—

1. Parallel to itself, so that the ends move up and down together.
2. About a horizontal axis through its centre, so that one end moves up as the other moves down, Fig. 4.

The parallel motion is of little importance, but owing to the gyroscopic action of the wheels the criss-cross motion has serious effects. Turning the axle about its centre causes the

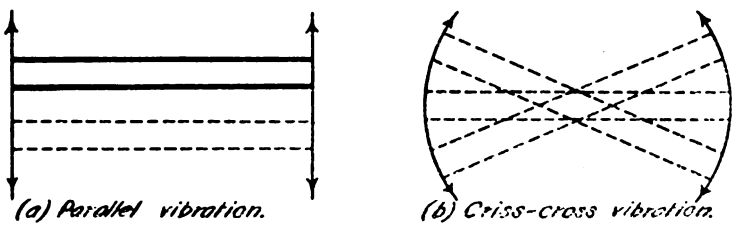

Fig. 4.

revolving wheels to move out of their vertical plane of revolution as they move up and down. The wheel that is descending is turned inwards by the gyroscopic action and *vice versa*. On reaching the ground the castor action tends to bring the wheel back into the straight, and this is assisted by the gyroscopic action on the other wheel.

The parallel and criss-cross types of vibration of the axle previously referred to have each their natural periods which depend on the distribution of mass along the axle, and on the mechanical characteristics of the springs at each end; either may be set up by a harmonic force of suitable period applied at one end of the axle, and such a force may be produced by a wavy road surface or some irregularity in a wheel.

It is found that the effect of replacing high-pressure tyres by low-pressure tyres is to reduce the natural period of criss-cross vibration of the axle; a similar effect is produced by

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increasing the mass at each end of the axle, *i.e.*, by fitting front wheel brakes.

The critical period for each type of vibration has been calculated for three typical cases, and these are set out in Table I, together with the speed in miles per hour at which, in each case, a wheel irregularity would produce such a frequency of vibration.

TABLE I.

Condition.	Parallel motion.		Criss-cross motion.	
	Critical periods. No. per minute.	Speed. m.p.h.	Critical periods. No. per minute.	Speed. m.p.h.
With high-pressure tyres, no front wheel brakes - - - -	520	47	690	61
With low-pressure tyres, no front wheel brakes - - - -	440	40	580	53
Low-pressure tyres, with front wheel brakes - - - -	420	37	510	46

From this table it will be seen that the change from high-pressure tyres to low-pressure tyres, on a certain car, produces a lowering of the critical speed at which criss-cross motion of the front axle might be expected from 61 miles per hour to 53 miles per hour. In other words, it might just be sufficient to cause this phenomenon of wheel wobble to occur within the normal speed range of the car. Moreover, by fitting front wheel brakes, the critical speed is still further reduced to 46 miles per hour.

The period of the parallel motion is also successively reduced by these changes, but this type of motion is relatively unimportant, compared with the unpleasant effects induced by the criss-cross motion.

At one time it was thought that front wheel wobble was due to an inherent defect in balloon tyres, but it is now known that

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the trouble is only to be expected if large, soft tyres are fitted, and no precautions are taken to prevent the development of the particular vibrations involved. The problem has been more fully dealt with in my paper on "Front Wheel Wobble."*

Solid Tyres.

Many would hardly expect the solid tyre problem to require Fourier series in its solution. Yet the internal stresses in the tyre cannot be calculated in any other way, and even then only very approximately. The rubber compound used must have a low hysteresis, or internal friction coefficient, so that only a small amount of heat will be developed. At the same time, it is not possible to use compounds having the very lowest internal friction, because they would not wear long enough, and would be cut too easily.

The large mass of rubber prevents the escape of heat, and it is quite easy to burn a solid tyre by running it at high speed, or by overloading it. In order to give the maximum possible length of service, it is necessary to sail as near the wind as possible in respect of internal friction, and in consequence, solid tyres ought not to be loaded more heavily than is specified in the makers' catalogue.

From what has been said of the need for keeping the degree of vulcanisation within rather fine limits, the difficulty of manufacture can be imagined. Rubber is a very bad conductor of heat, and a long time is required to bring a large mass of the material to a desired temperature. It is usual to cure (vulcanise) solid tyres in several stages of time and temperature, as, for example, two hours at 120 degrees C., one hour at 135 degrees C., and one hour at 150 degrees C. Even then special attention must be paid to the compound to avoid over-vulcanisation of the outside surface. This would lead to cracking at an early stage in the life of the tyre, and then to complete failure.

* Proc. Inst. of Automobile Engineers, vol. xix.

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Cushioning Capacity: Road Damage.

The flexibility of the tyre is of great importance to the road as well as to the vehicle. There is equal and opposite reaction

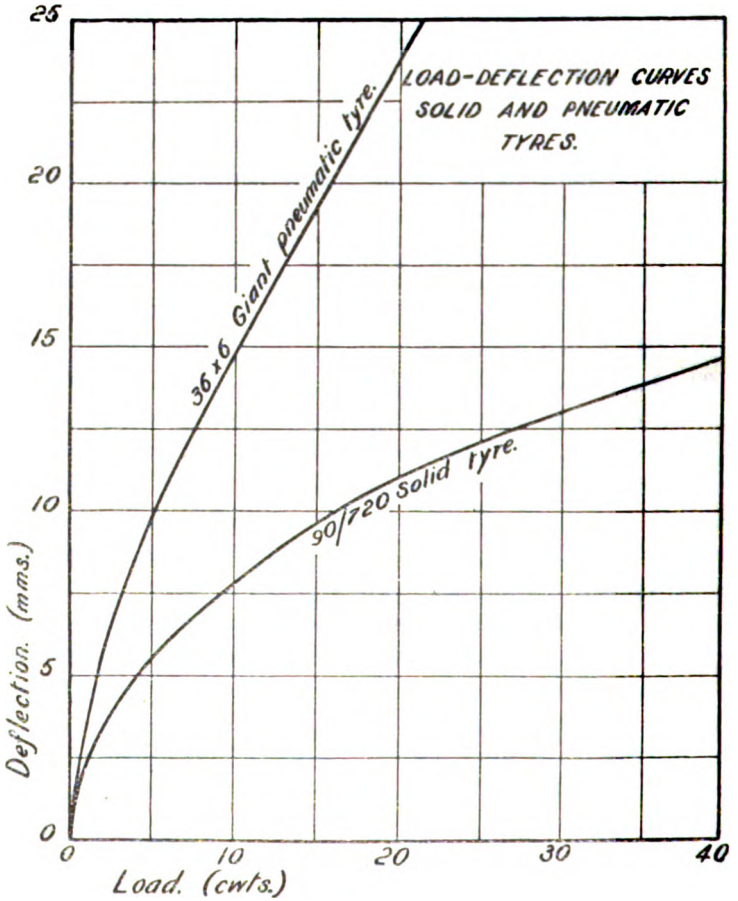

Fig. 5.

to every action, and a road shock is felt equally by both wheel and road. Many automobile engineers have already found it good policy to provide more flexible tyres (even at considerably

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greater cost) for their vehicles, because the reduction of road shocks so obtained enables a lighter chassis to be used to carry the same load, and the maintenance charges are also reduced. Road engineers are also tackling the problem in their own interests, and it is safe to say that in the course of a few years there will be either a voluntary or a compulsory change from the present hard solid tyres to a much softer kind, if not a complete change to pneumatic tyres.

It is interesting to note wherein lies the advantage of the pneumatic tyre. Fig. 5 shows the load deflection curves of typical solid and pneumatic tyres. Both types behave as springs, increasing load producing increasing deflection, or bending. The diagram represents in graphical form the compression of the tyres as the load on them varies. It will be seen that the pneumatic tyre behaves as a simple helical spring, the compression being almost exactly proportional to the load carried; but that the solid tyre becomes in effect a stiffer spring as the load increases. This is a serious drawback to the latter tyre.

Assume that, by reason of some irregularity, the wheel strikes the road with a certain vertical velocity. There will be a certain quantity of kinetic energy to be absorbed before the vehicle can be brought to rest (vertically). In the cases of the solid and pneumatic tyres referred to, the tyres will have to be deflected 0·55 inch and 0·95 inch respectively; and the maximum values of the reaction between the road and the tyre are 4,040 lbs. and 2,240 lbs. respectively. Much work has been done on this subject by the American Bureau of Public Roads, and it was found that the conventional solid tyre produced instantaneous reaction equal to five times the normal load, while the pneumatic tyre produced only $1\frac{3}{4}$ times the normal, under the same conditions.

From considerations of this kind, it appears that the most satisfactory criterion of cushioning capacity is the capacity to absorb energy without undue increase in reaction

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between road and wheel. The following figures illustrate the point:—

TABLE II.

Size of Tyre.	Deflection produced in absorbing 56 ft.-lbs.	Maximum reaction between tyre and road.
36 ins. × 6 ins. giant pneumatic -	0·95 in.	2,240 lbs.
90/720 solid - - - - -	0·55 in.	4,040 lbs.
30 cwt. for 850 cushion - -	0·55 in.	3,140 lbs.
30 ins. × 5·25 ins. balloon - -	1·26 in.	1,180 lbs.

Quite apart from these considerations, the area of contact of the tyre with the road is important on some types of road. A tarmac road, heated by the sun, would be "grooved" more readily by solid tyres than by pneumatic, simply because the load is concentrated on a smaller area.

CUSHIONING CAPACITY: THE PASSENGER'S POINT OF VIEW.

Much work has recently been done on the question of riding comfort, and many attempts have been made to determine the effect on the passenger of various alterations in the suspension system. The chief obstacle to the solution of the problem is the difficulty of devising and obtaining a suitable instrument; another complication lies in the fact that it is often a physiological rather than a purely physical cause that produces the most uncomfortable effect.

An instrument in use at present was constructed by the Cambridge Instrument Co.; its essential feature is a weight supported on a stiff steel spring, the movement of which is critically damped by electrical means and recorded on a celluloid film. The natural free period of the system is very short, and as the total movement recorded is very small (in the region of 1 mm. for an acceleration equal to that of gravity) the records are enlarged photographically for the purpose of measurement.

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The following figures obtained during a run at 20 m.p.h. over a short stretch of bad road (a) on solid tyres, (b) on pneumatic tyres, are typical of the results that may be obtained with this instrument. In this case the vertical accelerations recorded are shown in Table III.

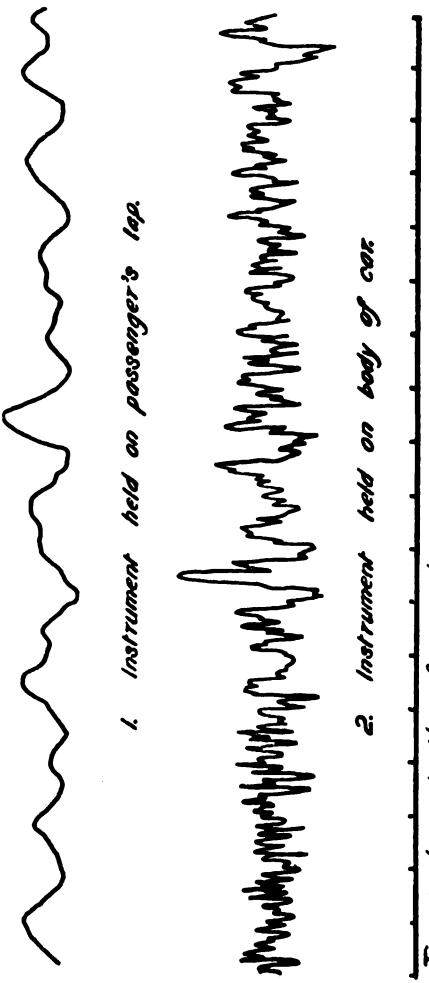

Fig. 6.

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TABLE III.

	On solid tyres.	On pneumatic tyres.
Maximum upward - - -	15 ft./sec.^{2}	15 ft./sec.^{2}
,, downward - - -	31 ft./sec.^{2}	23 ft./sec.^{2}
Total number of times an acceleration greater than 12 ft./sec.^{2} was recorded in a certain distance -	111	39

Fig. 6 shows two records which were obtained in a car travelling at 25 miles per hour over a very bad road. In case (1) the instrument was held in the passenger's lap, and in case (2) it was held on the body of the car. The actual maximum accelerations represented are approximately 30 ft./sec.^{2} and 60 ft./sec.^{2} respectively.

It is interesting to note that by suitably altering the spring strength and using the instrument on its side, it may be used to measure horizontal accelerations, *e.g.*, in braking tests. A typical record of this type is shown in Fig. 7, which was obtained in a car fitted with four wheel brakes on a level wet tarmac road. When the car was travelling at a steady speed of 40 miles per hour, the clutch was first disengaged, and then the full brake power was applied. The effect of both these actions can be seen in the record, the average retardation during braking being 17 ft./sec.^{2}.

THE ATTACHMENT OF THE TYRE TO THE RIM.

All pneumatic tyres may be divided into two classes, according to their method of attachment to the rim. These are (1) the well-known beaded-edge type, in which the bead is formed round a hard rubber core and moulded into shape to fit closely under the rim flanges. This forms a solid bead which, though hard, is still extensible, and, in fact, the only means of getting tyres of this type on and off the rim is by stretching the beads over the rim flanges. (2) The "straight-side" or wired type.

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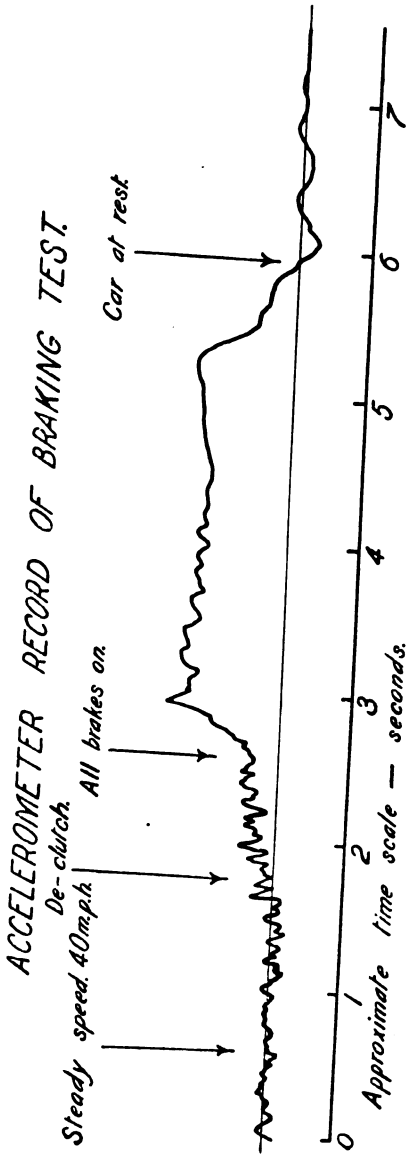

Fig. 7.

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The essential feature of this type (which is now rapidly superseding the beaded-edge type in this country) is the incorporation of strands of wire in the beads forming an inextensible band.

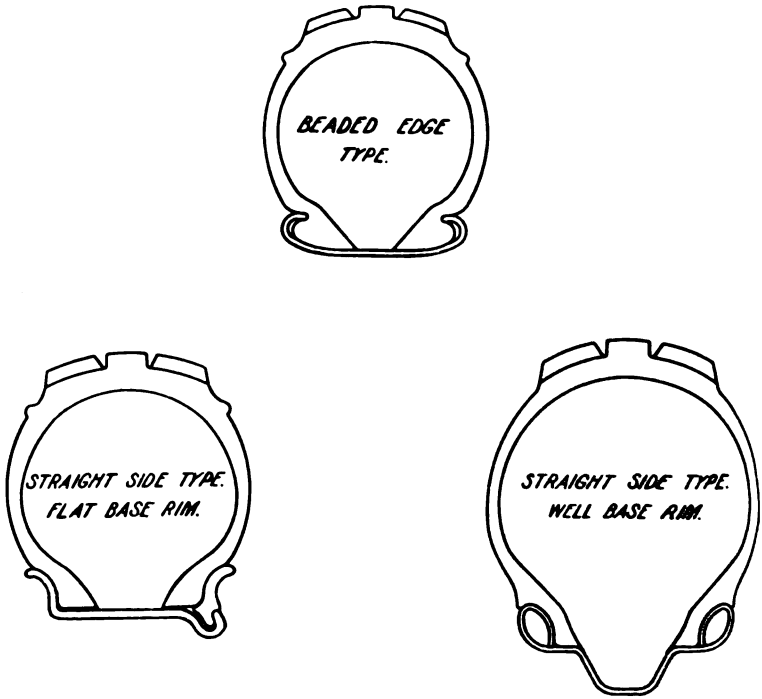

Fig. 8.

Rims for these tyres are of two main types: (1) the flat base rim with detachable flange, in which one flange is removable, thereby enabling the tyre to be pushed into position on the rim, after which the flange is replaced, locking itself into position by springing into a groove in the rim; (2) the one-piece well-base rim, which is the standard type constructed by the Dunlop Co., for use with balloon tyres. In this type the tyre beads rest on shoulders, between which there is a well. In

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mounting covers on rims of this type, the bead is lifted over the flange at one point and pushed into the well. This makes it possible for the bead at the diametrically opposite point to be lifted over the flange without injury.

A sectional diagram of each type of attachment is shown in Fig. 8.

The disadvantage of the beaded-edge type is the fact that it depends upon its inflation pressure to hold it in position on its rim. Any exceptional lateral stresses, combined with a low inflation pressure, may easily cause the bead toes to be displaced from their position, thus making it quite easy for the beads to be stretched over the flanges.

This danger does not exist with the straight-side type, as the tyre is virtually locked to the rim, unless the rim itself fails or the bead wires break.

The flat-base rim with detachable flange is somewhat heavier and more expensive than the beaded-edge rim, but the well-base type combines the advantages of both, *i.e.*, it is a one-piece construction, cheap, light, and gives absolutely secure attachment.

When the Dunlop balloon tyre was being developed, extensive tests were made with the well-base type of rim in order to establish this question of security of attachment. It was thought that the low inflation pressures for which the new types of tyre were designed might make the adoption of a beaded-edge construction unnecessarily dangerous, and this was actually found to be the case in practice.

A light two-seater car was driven round a hairpin bend of approximately 35 feet radius at speeds up to 18 miles per hour. This was found to be as fast as possible consistent with safety—a speed of 25 miles per hour would have been sufficient to overturn the car. The front tyre on the outside of the curve was used for the test, as this takes the severest strains in cornering.

On Dunlop 27 inches × 4·4 inches balloon tyres with well-base rims, the inflation pressure was reduced to 2 lbs. per square

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inch, and it was found impossible to make the tyre leave the rim. A large number of tests were carried out under these conditions, often in the presence of well-known automobile engineers and other men of wide technical experience, but in every case the cover remained securely in position and the tube remained inside it.

On 715 x 115 beaded-edge balloon tyres, the covers left the rim on one side, and the tube came out and "ballooned," even when the pressure in the tyre was 10 lbs. per square inch. The average motorist's tyre might easily drop to this pressure without his being aware of the fact, but when the pressure of a tyre drops below 5 lbs. per square inch it becomes very noticeable, both by the noise it makes and by the vibrations of the car.

As long as there is sufficient pressure in the wired-on type of tyre to keep the beads on the shoulders of the rim, it is impossible to make this type leave the rim.

Figs. 9 and 10 are general views of the corner used for the test, and Fig. 11 is a "close-up" snapshot of the deformation of the deflated tyre during a test.

It was thought that a sudden *total* deflation might have a serious effect, and this point was also thoroughly tested. A car was driven at speed along an ordinary road with one tyre totally deflated. In order that the tyre may leave the rim, it is necessary for the bead to drop into the well at one point, and become distorted from a circular into an elliptical shape for the diametrically opposite point to be lifted over the flange. Many miles were driven with a totally deflated tyre, and it was found that the centrifugal force acting on the cover was sufficient to keep the wire beads circular in shape and, therefore, in their places on the rim shoulders.

On racing cars, straight-side tyres on well-base or flat-base rims are practically a *sine qua non* in these days. Under the strenuous conditions of racing, beaded-edge tyres, even when fitted with numerous security bolts, are highly dangerous.

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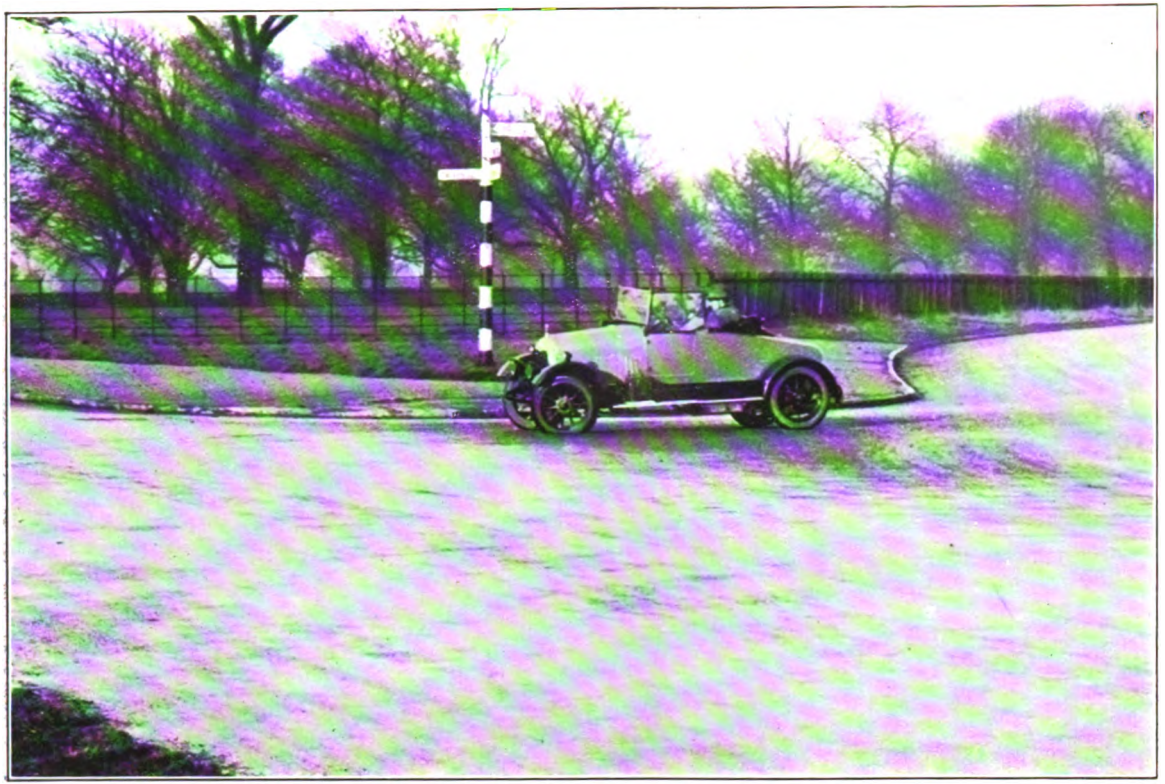

Fig. 9.

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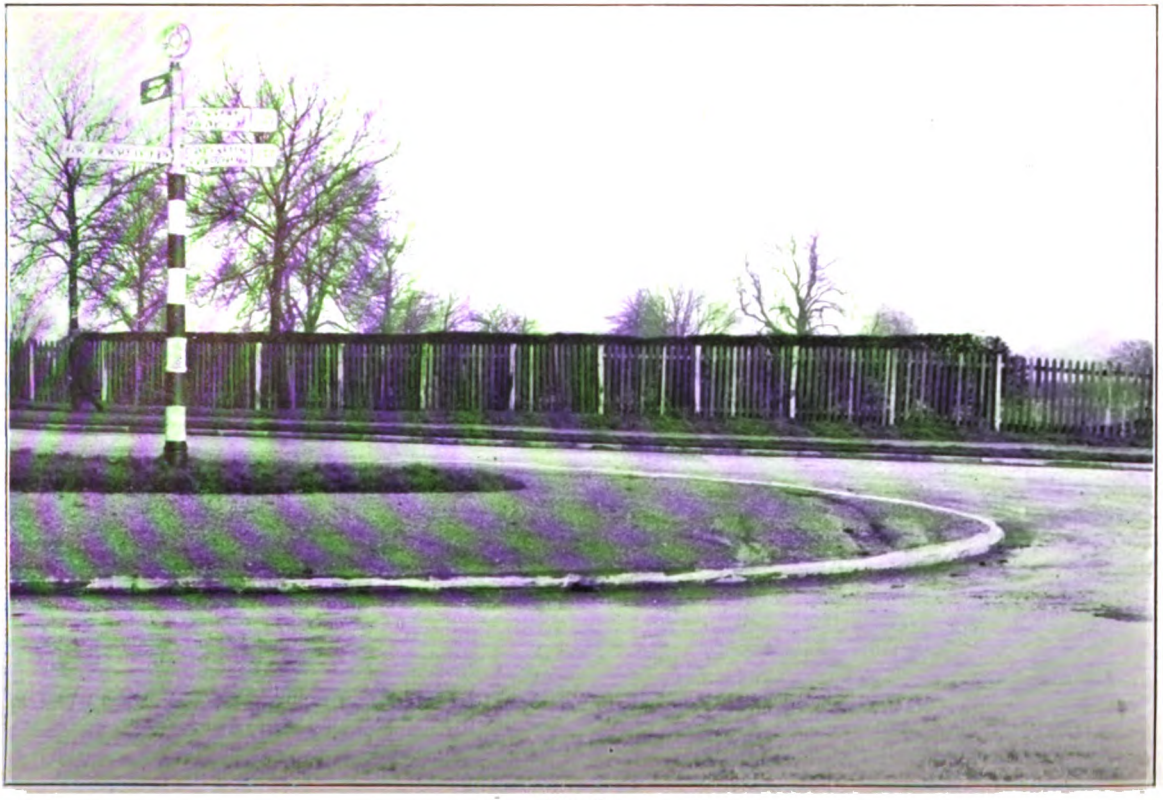

Fig. 10.

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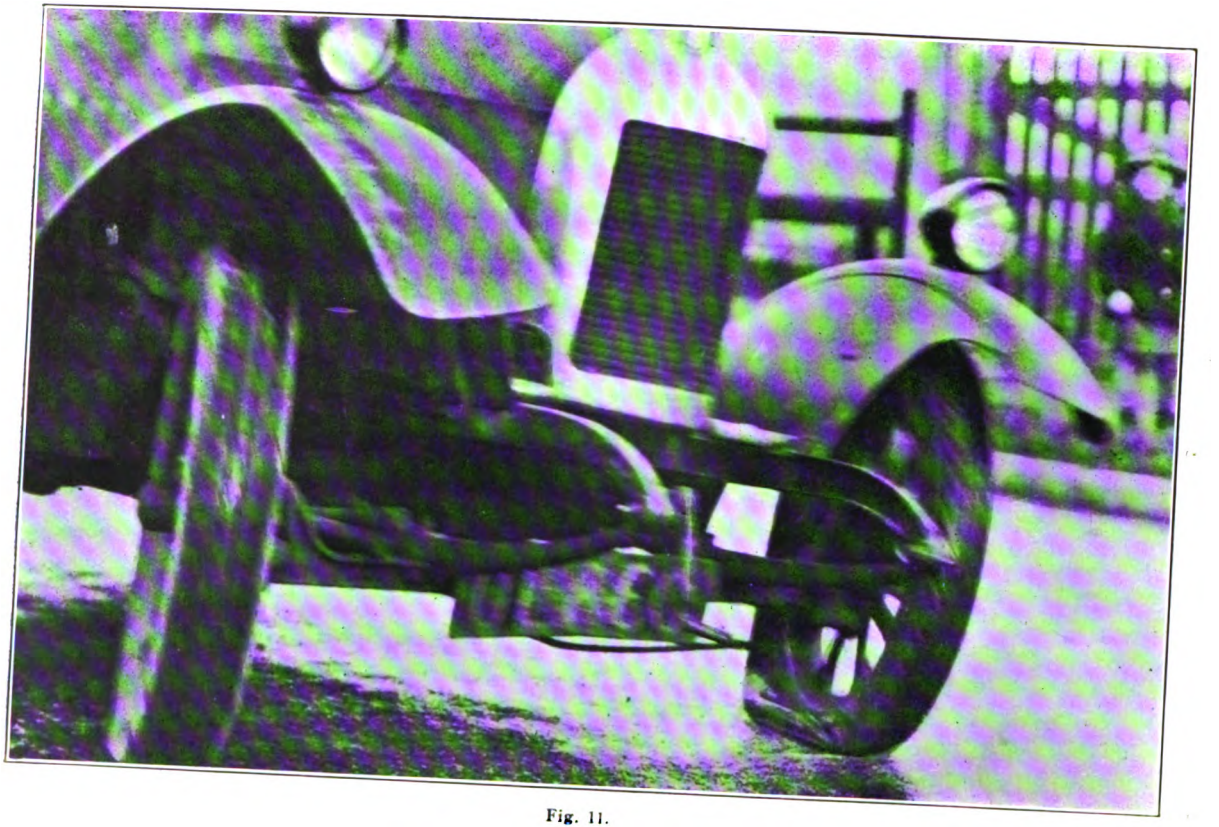

Fig. 11.

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Some further experiments with the well-base rim and wired-on tyres have recently been carried out on a racing car at Brooklands track, demonstrating the security of this type at a low inflation pressure, even on a wildly skidding car.

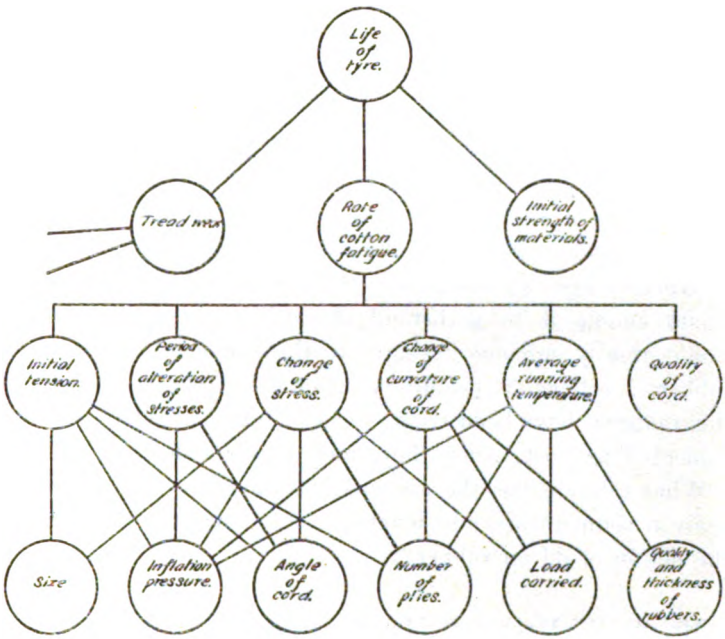

Fig. 12.

Conclusion.

I regret that considerations of time and space have not allowed a much fuller treatment of the problems referred to, but I shall feel satisfied if I have succeeded in creating interest in the subject.

The Dunlop Rubber Co. feel that they have nothing to lose and everything to gain by awakening intelligent interest in the goods they produce, and it is for this reason that such papers as the present one are willingly allowed to be published.

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Discussion.

Mr. J. H. HUNTLEY (Member): I should like to ask Mr. Healey if he could explain why, on the tread of a tyre which is formed of a series of diamond-shaped projections, the wear at the back of each projection is greater than that at the front. The effect of this irregular wear is to give the tread of the tyre as a whole a somewhat saw-toothed appearance.

Mr. C. R. H. BONN (Associate Member): The valuable properties of rubber are not unknown to the engineer, and at one time it was widely tested, but it fell into disuse for many purposes owing to failure due to oxidation, effects of destructive agents, frost, etc. A treatment of rubber which would enable it to withstand the destructive action of oil would greatly enhance its value to the engineer. Vulcanised rubber, I believe, is peculiarly affected by frost. Springs of this material have been tried, and gave great satisfaction until subjected to frost, when they immediately failed.

What relation has the amount of sulphur to the rubber for a given temperature and length of cure, and what exactly is the action of oil on rubber?

Mr. W. W. MARRINER (Member of Council): As Mr. Healey has invited questions on his most interesting paper, perhaps the following might be of interest to the meeting. If a layer of sulphur be distributed over a sheet of rubber, and both raised to a certain temperature, will the rubber be cured uniformly throughout, or will the upper part of the sheet have more sulphur in it than the lower part?

When a car is laid up for any length of time the tyres seem to deteriorate, and the first trip out on the road is sometimes rather disastrous; first one tyre gives out and then another, and especially is this the case with inner tubes, which often fail because of a number of minute cracks which make their

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Mr. W. W. Marriner.

appearance in them. Is that fault peculiar to inner tubes, or is it due to deterioration from age?

Is there anything in the pattern of a tyre? Although I do not drive at more than 30 miles an hour, I have noticed no more slipping with a smooth tyre than with a fancy diamond-patterned rim.

When Mr. Healey was demonstrating front wheel wobble on his model, he said that he had purposely put the wheels out of balance so as to magnify the amount of wobble. Then he altered the relative positions of the wheels and got another kind of wobble, which occurred at a different speed of revolution. If the wheels are accurately balanced, will they wobble at all? I can understand that if there is a disturbing force, and it synchronises with the period of the springs, a periodic motion will occur similar to that which can be obtained by a weight suspended by a piece of rubber. If the weight is made to dance by synchronising the impulses, a very considerable movement can be obtained, although each impulse may be very small.

From Fig. 2 it is seen that when a motor car wheel is run at a very high speed the tyre changes shape. If a wheel, which is accurately balanced when at rest, is revolved at a high speed, will it extend equally all round in a radial direction? It is quite possible that when a car is travelling at high speed the wheels have not the same balance as when at rest, due to the unequal extension of the tyre by centrifugal action, and this may be the cause of the wobbling at high speeds, although the balance of the wheels may be perfect when at rest.

Mr. C. H. Wright (Member): Mr. Healey states with regard to the latex globules that "the coagulated particles cohere very strongly, and cannot by any known means be separated without being partially destroyed." When rubber perishes, what has happened to these latex globules; are they themselves broken up?

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Mr. C. H. Wright.

I am interested in an apparatus employing small containers of thin rubber to carry water. The containers are enclosed in an instrument, and are, therefore, in the dark, but ageing shown by "shortness" sets in sometimes early on, and sometimes only after a very long period. In some cases the rubber will tear readily under slight stretching, while in other cases it is extremely tough, even when a year or two old. I suppose that light is very active in ageing rubber, and consequently a rubber object kept in the dark should not age so quickly as if it were exposed to light. It is this variable ageing of rubber articles which is troublesome to users of rubber for mechanical purposes, and any information from Mr. Healey as to how ageing may be retarded will be welcome.

With regard to front wheel wobble of the motor car, are not simple means available for damping this out?

Mr. JOHN S. BROWN, M.B.E. (Member): The title of this paper allows scope to roam freely over every period in the life of the tyre; and while there is much of interest in the progress in rubber mixtures and in the model demonstrating wheel wobble, I will pass directly to a matter more intimately associated with normal everyday service. Thus we are instructed to examine the covers at frequent intervals for road cuts, to remove any embedded flints, and to apply a tyre-stopping to prevent growth of the damage. May I inquire for the name of any material which will give reasonable service as such a stopping? Further, the position with regard to vulcanising appears to be little better; even on a simple tube repair about 25 per cent. are failures. Arising out of this, can Mr. Healey say whether the various cures and accelerators introduce variables which make it difficult to judge the correct treatment when in the repairer's hands?

Mr. T. H. HILL (Member): I have been interested in ships' sidelights for many years, and in their use have tried all

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qualities of rubber, but in every case deterioration of the rubber ultimately took place. The rubber in sidelights is exposed more or less to salt water and ozone, and is in contact with brass, and subjected to a continuous and steady pressure. Perhaps Mr. Healey will state if this combined oxidation and pressure is the cause of the rubber losing its toughness and becoming brittle. I have noticed in parts of machinery where rubber jointing is used that it deteriorates more rapidly under a heavy load than under a light one.

Mr. F. L. MacLaren (Member): I was greatly interested in the demonstration given by Mr. Healey of front wheel wobble. Seven or eight years ago, six American-built cars of a certain type, namely, a two-seater of 22 horse-power, were sold in Glasgow, and I knew one owner of a car of this make. My brother advertised for a two-seater car, and this owner came along with his for sale. On being questioned about the car, he said that when he drove it up to 55 miles per hour it suddenly rose off the road and came down at right angles to the track. He further said that he did not know the cause of this eccentricity, but he advised my brother not to buy the car if he intended to drive it up to this speed. After using it for a while, my brother sold it to me, saying that he knew that I had more sense than to wish to drive it at an excessive speed. When I drove it at 25 miles per hour, however, it started to straight wobble, and on thinking over the matter I decided to lengthen the body, when a friend of mine advised me to alter the springs instead. There were four leaves in each set of springs, and I altered the back set to five leaves, which absolutely cured the wobble up to 35 miles per hour. Whether wobble would have developed at a higher speed than that I cannot say.

Mr. J. D. Hamilton (Student): Mr. Healey has given some very interesting information on, and demonstrations of, the

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Mr. J. D. Hamilton.

phenomenon of speed wobble on cars, particularly the "tramping" due to the criss-cross motion of the axle, and consequent loss of steering control. Perhaps Mr. Healey has had experience of speed wobble on motor cycles. This case is not quite analogous, because, though steering control be lost, it cannot be due to the wheels alternately leaving and touching the ground, as only one wheel is concerned.

I wonder, therefore, if the wobble may be due to the wheel being unbalanced, with consequent displacement of the centre of gravity, since there cannot, apparently, be any criss-cross vibration of the axle, which is not freely suspended, as is the car axle, from its springs. If this type of wobble has been investigated, at what conclusion have the experimenters arrived?

Mr. JAMES A. MCCASH, B.Sc. (Student): Mr. Healey quotes figures showing the rate of wear of the tread of certain tyres, namely, 1 mm. per 1,000 miles. These figures presume considerable accuracy of measurement. Would Mr. Healey explain how he arrives at this result?

Mr. W. H. ALLEN: I am of opinion that Mr. Healey's paper ought to be very helpful in giving the general tyre user an idea of pneumatic tyre technique. It should be especially valuable in helping him to understand some of the abuses to which tyres are subjected in service. It is very obvious that the average tyre user could, with the exercise of reasonable care, very materially prolong the life of his tyre equipment, and anything which will give him the benefit of some general experience and safeguards is well worth general distribution, although it is difficult to put such information into a form that will obtain wide publicity and thoughtful study on the part of the individual user.

Mr. GEORGE H. LANCHESTER: Mr. Healey states his case so clearly and his deductions are so convincing that he leaves

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Mr. George H. Lanchester.

little scope for discussion. His digression on the subject of wheel wobble is of interest, not only to automobile manufacturers, many of whom have but a vague understanding of its cause, but also to the motoring public, as, judging by the letters appearing in the automobile press, theories as to the cause of wheel wobble are various and wonderful, and in most cases effects are hopelessly confused with causes. In support of Mr. Healey's conclusions as to the cause of wheel wobble, it is worthy of remark that low-pressure tyres and front wheel brakes came into vogue concurrently, and low-pressure tyres have undoubtedly been condemned as the cause of a defect to which they are merely contributory, and for which front wheel brakes are primarily responsible. It is interesting to observe the action of front and rear axles on the road. Whereas the rear axle, with its mass more uniformly distributed throughout its length, almost invariably vibrates parallel to itself, the front axle, with its mass concentrated at the two ends, more frequently vibrates criss-cross than parallel.

In the present paper Mr. Healey gives a most interesting and instructive insight into the problems which confront the tyre manufacturer, and in his investigations on "Front Wheel Wobble," referred to on page 705, has rendered the automobile industry an outstanding service.

Mr. H. F. Schippel: The first part of Mr. Healey's paper is a very interesting dissertation on tyre technology. It indicates the salient features in its "gamut and diapason" of tyre problems, ranging from the bass note of the blow-out to the shrill voice of the expiring inner tube. It gives the non-technical reader a glimpse "behind the scenes" in this modern romance of the tyre industry, and also gives some well-deserved publicity to the men who are working out the intricate problems of the industry.

Mr. Healey touches upon the very important problem of failure at the junction between rubber and cotton, which

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Mr. H. F. Schippel.
causes the destruction of many an otherwise well-balanced tyre. This problem offers a profitable study to those mathematical physicists who have in the past studied the problem of the anchorage of pigments to rubber.

I may say that Mr. Healey's figure for rate of tread wear corresponds with average results obtained in this country (U.S.A.), but in many cases, particularly in combinations of good tread designs and compounds, the mileage developed may exceed this threefold. To the list of factors governing abrasive wear of the tread may be added "intensity of road contact pressure," as distinguished from inflation pressure. This is also one of the factors in the scientific design of tread patterns. I hope the day will come when not all patents on tread designs will describe them as ornamental and decorative. Those based on such principles will sooner or later become obsolete.

The latter part of Mr. Healey's paper is an instructive discourse on problems that are even yet not entirely solved, such, for instance, as:—

Resistance to wear *versus* resistance to skidding.
Balloon tyre tread wear.
Front wheel vibration.

In commenting on the first of these problems, Mr. Healey does not mention that the average thickness of the film of water or mud between the tyre and the road depends on the average distance the film has to travel in order to be squeezed out, and, therefore, the more frequent the provision of slots in the rubber surface, the less that average distance becomes, and hence the better the non-skid value of the tread. I would consider this equally important to any of the other factors, but do not suggest that this idea be carried to excess.

There has been some controversy in this country (U.S.A.) on the subject of balloon tyre tread design. One faction advocates unequivocally the flat tread profile, while the other

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Mr. H. F. Schipped.

praises with equal earnestness the round profile. The operating characteristics of these opposed profiles are different on front and rear wheels. The greater load is usually carried by the rear tyres, hence the vertical deflections are greater; they also travel in a straighter path, with less side sway, and they carry more unsprung weight. These characteristics, which distinguish rear wheel operation, do not seem to differentiate the wear of these designs so much as do the front wheel characteristics. The latter are:—Greater lateral motion due to steering effect, wobble, camber, and toe-in. It is my personal experience that in front wheel service the flat tread profile is superior, as it seems to produce a less irregular wear. My method of classifying tread profiles is to determine the percentage of normal load at which the full width of the tread makes contact with a level road surface.

I was very much interested in Mr. Healey's explanation of the cause of rotary oscillation of the front wheels and axle, but was of the opinion that it was the gyroscopic action of the wheels due to the steering oscillation which produced the rotary oscillation. But as they occur simultaneously, it may be difficult to determine which is the cause and which the effect.

Mr. HEALEY: In reply to Mr. Huntley, I may say that when a pneumatic tyre is travelling at 30 miles per hour the wheel has a certain angular velocity. Since the extreme radius of the tyre is smaller where the tyre is in contact with the ground than at other places, the actual speed of the tread is less at that point. In practice, the tread travels at a speed of about 31 miles per hour, except when it touches the ground, and travels at 30 miles per hour. Consequently there is a tendency for each stud to be pushed backwards as it comes into contact with the ground, the result being a small distortion of the stud and a localisation of contact pressure on its forward end. As soon as the forward end leaves the

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ground, the stud recovers its undistorted shape, and a slip of the rear end occurs. In addition, the whole stud must be accelerated, and this cannot occur until the contact pressure has become small, *i.e.*, after the forward end has left the ground. The rear end is, therefore, compelled to slide on the ground, and is worn away. It is interesting to note that the process is cumulative, for the wearing away of the rear end produces a still greater localisation of pressure on the forward end.

Mr. Bonn refers to the destructive action of oxidation and of oil on rubber which is well known, but frost has little effect, if any, on vulcanised rubber. I need only refer to the use of tyres in very cold climates to prove the latter point.

The proportion of sulphur to rubber in tyre treads is usually about $\frac{1}{25}$th, and the length of cure about 90 minutes at a temperature of 145 degrees C. Oil has no chemical action on rubber. The deterioration produced is due to absorption and destruction of the fibrous texture of the rubber.

With regard to Mr. Marriner's first question, everything depends on the thickness of the sheet, the temperature applied, and the time of vulcanisation. A sheet about ·02 inch thick might be uniformly vulcanised if great care were taken in applying the sulphur and in controlling the temperature.

A car laid up for a long time should not be allowed to stand on its tyres, even if they be kept properly inflated. The failure observed is due to deterioration by age.

Wheel wobble is less likely to occur with balanced wheels and tyres, but it is not entirely eliminated. Other circumstances may impart the necessary stimulation. Centrifugal action at high speed probably increases the asymmetry of tyres, but I have not found any case of a balanced tyre becoming out of balance at high speed.

When rubber perishes, the globules themselves are destroyed. There is nothing mysterious in the variation of the ageing

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qualities mentioned by Mr. Wright in connection with rubber containers. The manufacturers should be consulted.

Front wheel wobble can easily be damped out, and several devices for this purpose have been protected by patents.

Mr. Brown seems to have experienced trouble through tyre damage. In the nature of things, a repaired tyre cannot be as good as an undamaged tyre. It is impossible to ensure a satisfactory repair without the attention of an expert in each case.

Mr. Hill refers to the deterioration of rubber in sidelights. Salt water, ozone, the copper constituent of brass, and continued distortion under pressure represent the most powerful destructive combination that can be imagined. If the rubber be protected from the brass and from the water, it will probably last for a satisfactory period.

With respect to Mr. McCash's question, accuracy is obtained by measuring large numbers of tyres and taking the average.

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THE DESIGN OF HIGH-SPEED MOTOR BOATS.

By W. G. A. Perring.

4th May, 1926.

Introduction.

Motor boats built for high speed, although perhaps differing from one another in many respects, may be broadly subdivided into three classes, depending upon their shape. Their hulls are characterised by the shape of the transverse section, and in particular by the planing surface, which may be flat, "vee," or of "inverted vee" form. Generally the bottoms of the last two classes flatten out towards the stern, and over the after portion, therefore, all types differ very little from one another. Sometimes the vee type will change into the inverted-vee type, and so combine the two forms.

The inverted-vee type, which is a development of the "Viper" boats, was first employed for speed work in America, and its excellent sea qualities, even in quite heavy weather, earned for it the name of "sea sled." These boats are not very well known in this country, and although a number of them have been constructed, they have almost invariably been built for service abroad. A few notes on their characteristic features may, therefore, not be without interest to the members of this Institution.

General Requirements.

Before describing in detail the hull construction of the sea sled, it may be worth while to consider briefly some of the general requirements which all high-speed craft must satisfy.

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Naturally they must be designed to carry engines of high power, and be able to withstand the large impact forces set up when running in anything but absolutely calm water. The structural arrangements of the hull, therefore, require more than ordinary consideration.

While it is essential that every part of the structure should have the requisite strength, the weight of all parts must be reduced to the absolute minimum, and the weight of small details cannot be overlooked as unimportant. The necessity of keeping down weight without sacrificing strength will be realised when consideration is given to the balance which must be arranged between the weight, power, and speed.

To obtain high speed it is necessary that the boat should plane, and the planing speed is primarily determined by the load to be carried and its relation to the planing area. It is obvious, therefore, that the heavier the boat, or the machinery, the higher will be this planing speed. Linked with the weight, as items of primary importance, are the planing area, length, beam, and distribution of the load.

The planing area is dependent on the last three items, but the beam and the load carried, because of their influence on the running angle of the boat, govern to a large extent the effective planing area. Length has a rather indirect influence upon the area, since, at planing speeds, the forward end of the boat rises completely out of the water, the boat lifts bodily and runs almost entirely upon the after portion of the bottom.

A little consideration will show that the running angle, and general rise of the boat when travelling at high speed, determine the length of the planing area, and since this area is dependent on the load and speed, length is in a rather complex way bound up with beam. Consequently, the length-to-beam ratio of all fast craft does not vary greatly, and a ratio of about four to one, which is fairly common, has been found quite satisfactory in practice.

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To provide a good planing surface, the bottom should be flat, or nearly so, and to be efficient it should meet the water at an angle of incidence of between 3 and 4 degrees. In practice the angle is largely controlled by the distribution of the load, and a boat that readily trims back to an efficient planing angle will plane earlier than another which has the weight disposed too far forward. On the other hand, it is not desirable that the running angle should be large, which may happen if the boat trims back too soon. When this occurs the planing efficiency is reduced at the higher speeds, and more power is required than would otherwise be necessary.

The hull should be kept as free as possible from external appendages, as when fitted they may form a considerable percentage of the total resistance. To reduce the surface resistance of a boat, steps are frequently fitted to the hull, and the boat then runs on the edges of the steps. With this arrangement, it is sometimes necessary to ventilate the steps in order to obviate the tendency to create a suction, thereby increasing rather than decreasing the resistance.

The configuration of the waterlines forward should be arranged to cause the minimum wave disturbance, and the keel section kept fine for a sufficient distance abaft the stem to prevent the angle of the waterline in the running position becoming large. The flow of water to the propeller should be unrestricted, and here again special attention must be paid to the shape of underwater fittings so as to minimise resistance. Wind resistance is also a serious item at high speeds, and care is necessary in designing the upper works and wind screens to avoid a useless expenditure of power.

A sufficient margin of stability must be provided to allow for any virtual reduction in the metacentric height occurring at high speed. The margin of stability should also admit of the boat being turned and manœuvred without these motions causing excessive heel.

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Sea Sled Type of Motor Boat.

Sea sleds are usually built with vertical sides, the bottom meeting the sides sharply at the chines. The vee of the bottom gradually flattens out towards the stern, and over the after portion of the boat provides a slightly veed planing surface, extending from chine to chine. This surface, except for some very small cooling-water scoops, can be kept entirely free from appendages.

At the forward end, the inverted-vee forms with the water surface a funnel-shaped opening. This opening traps a considerable volume of air as the boat advances, and the "pocket" so formed helps to give the boat its remarkable sea qualities, enabling it to maintain its speed without pounding in heavy weather.

As the straight vertical sides forward meet the bottom sharply at the chines, there is little apparent water disturbance at the bow in the running condition. Consequently, the steersman has an uninterrupted view of everything in front of him. The normal vee type of boat, owing to the angle at which the water meets the form, throws up on either side a bow wave of considerable dimensions, accompanied by a large amount of spray, but with the sea sled any disturbance forward is driven inwards by the sloping bottom of the boat.

The inverted-vee type of construction results in the water-line area having a very large moment of inertia about a fore-and-aft axis. Consequently, a sea sled will have a comparatively high metacentric height. Since all fast boats have their maximum beam aft, and trim at full speed so as to run only on the after portion, there is probably little difference between type vee or inverted vee, as far as stability is concerned. The high initial stability, however, makes the latter type useful for slow runabout services, or as dinghies, since stepping on and off them causes very little heel or trim, no matter at what position the change of weight may occur.

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Sled boats are usually fitted with one or more surface propellers, and the arrangement has proved very satisfactory. The advantages of such propellers are accessibility and portability, while there is no loss of speed from the resistance which in normal boats is set up by the shaft brackets and bossings. The angle of the shafting is also very much less than with a submerged propeller, as the shafting is carried out through the transom, and the stern bearing may be incorporated without difficulty into the transom framing. The surface propeller, therefore, obviates cutting the keel, or bottom of the boat, and allows the motor to be placed well aft, without thereby incurring excessive shaft angles.

A large rake on the shaft changes the virtual pitch angle of the propeller blades as they vary their position during a revolution. This sets up an uneven propeller torque which tends to produce vibration. Where the propeller diameter is restricted by limitation of draught, it is quite possible that the surface propeller may be employed with advantage on boats other than sleds.

Sled boats are usually steered by side plate rudders which streamline into the form and cause practically no disturbance of the water when in the neutral position, and these rudders effectively control the boat when under way, with very little loss of speed. Once the helm is put hard over, the fact that the rudder and boat act together in producing turning-moment renders the boat easy to manœuvre.

Hull Construction and Propelling Machinery.

The sea sled is of extremely simple construction, and the shape of hull lends itself to easy fitting of the strength members and accommodation of the machinery. General features of the design are illustrated by Figs. 1 to 6.

Figs. 1 and 2 show the profile and general arrangement plans of a 22-foot sea sled of normal design. The boat has a single screw of the semi-submerged type, and with a Hall-

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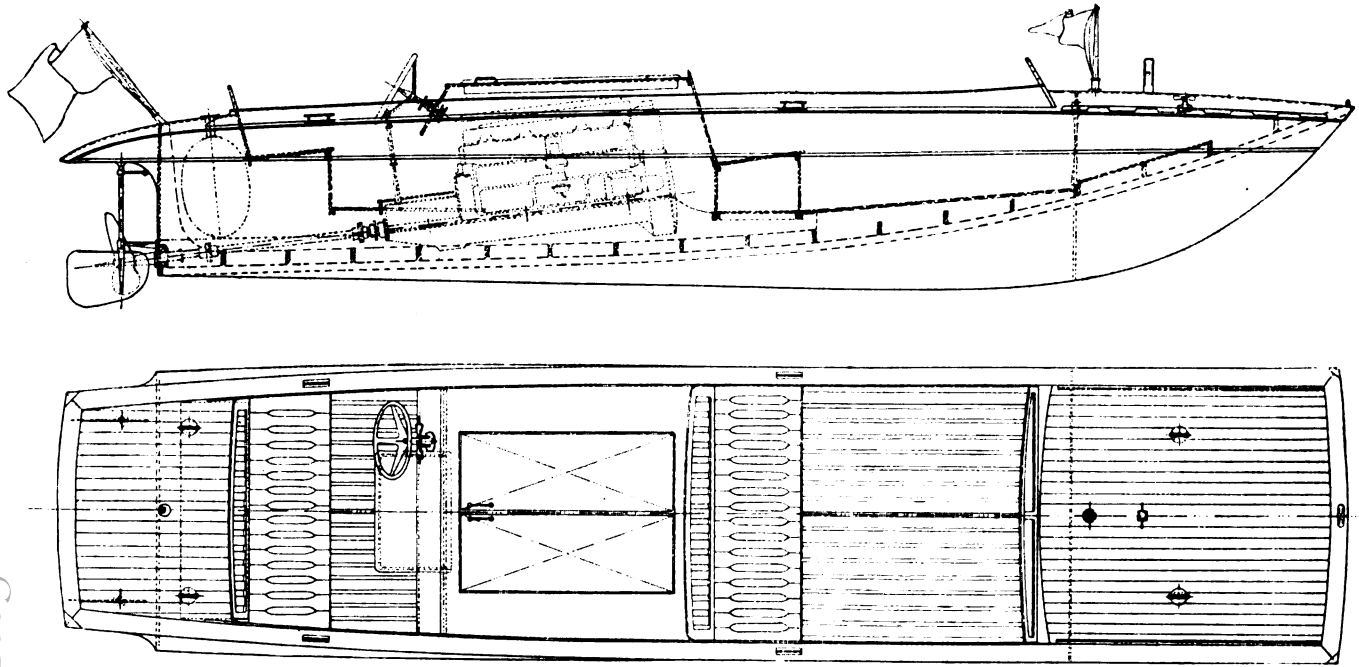

Figs. 1 and 2.—22-foot Sea Sled—Runabout Type.

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Scott 100 h.p. motor attains a speed of over 30 miles per hour. It will be seen that the driving and steering arrangements of this boat are planned to approximate as closely as possible to those of a motor car. The motor, which has an electric starter, is controlled by levers on the steering column, and in stopping, starting, and regulating there is very little to distinguish the action from that of a car.

Figs. 3 to 6 show the general arrangement, profile, plan, and sections of a high-powered cruiser type of sled, having the following dimensions:—

Length over all - - - -	50 feet.
Length between perpendiculars -	47 feet 6 inches.
Beam, moulded - - - -	11 ,, 6 ,,
Depth, moulded - - - -	4 ,, 3½ ,,
Displacement - - - -	8¾ tons.
Draught, extreme - - -	2 feet.

In building this particular boat, the hull was constructed bottom uppermost. Uprights were erected at each frame, and the frames and transverse bulkheads were placed in position and temporarily secured to these standards. The framing for the most part is of ¾-inch Honduras mahogany, but in the saloon and under the motor it is of 1-inch teak. The frames were built up flush fitting, and strapped at the corners and the keel with double steel-coated $\frac{3}{16}$-inch plymax straps. Typical frames are shown in Figs. 5 and 6. Fig. 5 is a section just forward of the saloon, and Fig. 6 a section through the engine compartment.

The keel, stem, stern, transom post, and gunwales were fitted into position as soon as all the frames were assembled, and these parts were rabbeted to receive the planking. Before planking, all the internal strength members to take the motors were secured in position. These were built up before fitting into the boat, and were got into place by threading them through over the floor tops. The stringer pieces were

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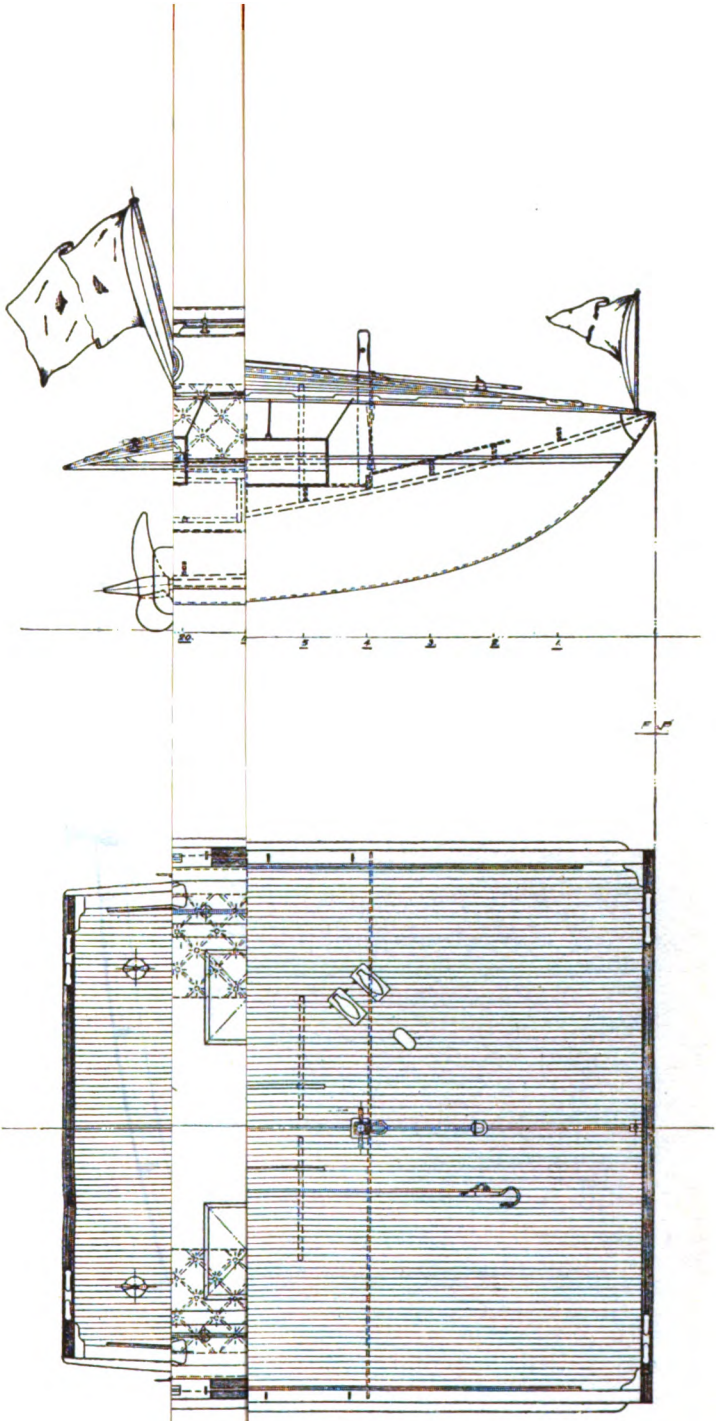

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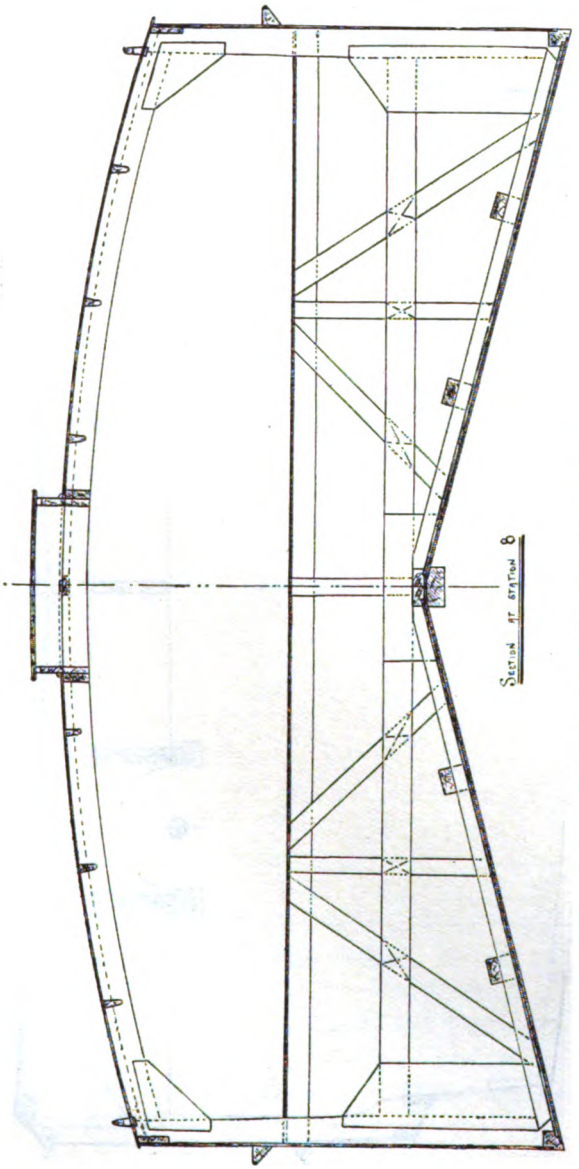

Fig. 5.—50-foot Sea Sled—Cruiser Type.

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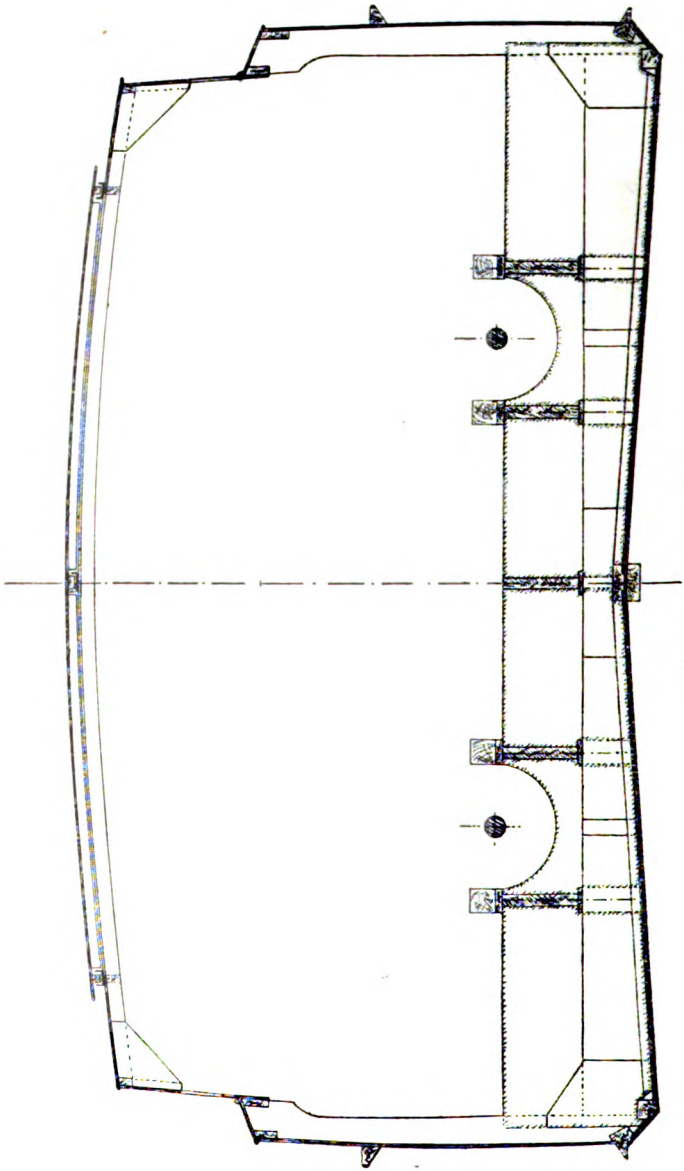

Fig. 6.—50-foot Sea Sled—Cruiser Type.

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carried well forward and right aft to bind the hull together and distribute the stresses transmitted from the motors. Timbers were fitted midway between the frames, and finally, when all parts had been clench fastened, the boat was planked.

The bottom planking is built up of two skins, separated by calico, the inner thickness being of mahogany and the outer thickness of teak. The sides and transom are of mahogany. The transom is very stiffly framed, with rock elm corner and bottom members braced to the chines, the actual transom plank being fitted finally in place merely as a closing panel. Building the boat upside down in the manner described enabled all the inside work, the girders, chines, etc., to be clenched off while they were easily accessible, and the planking to be placed in position more simply than if it had been secured from underneath.

Had there been sufficient head room and lifting arrangements, the boat might have been turned over in the shop, but to meet the existing conditions it was launched bottom uppermost, turned over in the water, and afterwards hauled up in the slip for the flats and decks to be planked, the shelters and saloon to be fitted, and the machinery installed.

The machinery consists of two Liberty motors, arranged to drive twin surface propellers, each of 36 inches diameter and 36 inches pitch. The engines are of the V-type, each rated to develop 400 h.p. at 1,800 r.p.m., and one engine complete with reversing clutch weighs 1,350 lbs. The power is developed in 12 cylinders, each 5 inches in diameter by 7 inches stroke, each motor being a self-contained unit equipped with water- and oil-circulating pumps, an air pump to maintain the petrol supply, and a generator to keep the starting battery charged and to supply the necessary current for ignition. The propellers are directly coupled to the motors through a clutch drive, fitted with reversing arrangements, each motor being installed as a separate unit, not only as far as control is concerned, but as regards the water-cooling

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and lubricating-oil systems also. The throttle and ignition controls are arranged side by side on control panels placed near the steering position. The control arrangements are fitted in duplicate, so that it is possible to drive the boat either from a position forward in the saloon or from the cockpit aft.

Petrol is fed to the motors under a slight pressure of air maintained in the petrol tanks, and when the motors are running this pressure is automatically maintained and adjusted by the motors. An air pump to provide the necessary pressure in the tanks for starting is fitted in both control positions. The motors are started electrically, all the necessary starting and control arrangements being grouped together and placed within easy reach of the man at the wheel. Figs. 7 and 8 show the boat at different stages of construction. On trial this boat attained a speed of 40 knots in a short steep sea. Its performance as a sea boat was in every way satisfactory, and there are undoubtedly possibilities for boats of this type.

In America such boats have been developed as passenger carriers for work at sea, and in shallow rivers. Another development which might be mentioned is their possible application as slow-speed cargo boats for work upon canals and rivers. They are specially suited for this type of work, because the absence of the usual bow disturbance preserves the banks of the waterway from erosion.

It is, of course, impossible to embrace everything within the scope of a paper of this description, but it is hoped that sufficient has been recorded to introduce these rather interesting craft, and to illustrate how they fulfil the necessary requirements for a boat in which speed and seaworthiness are desiderata.

Discussion.

Mr. David Nicolson (Member): I do not consider Mr. Perring's paper to be very informative. The title appears to be a misnomer, as the paper deals with the sled type of boat

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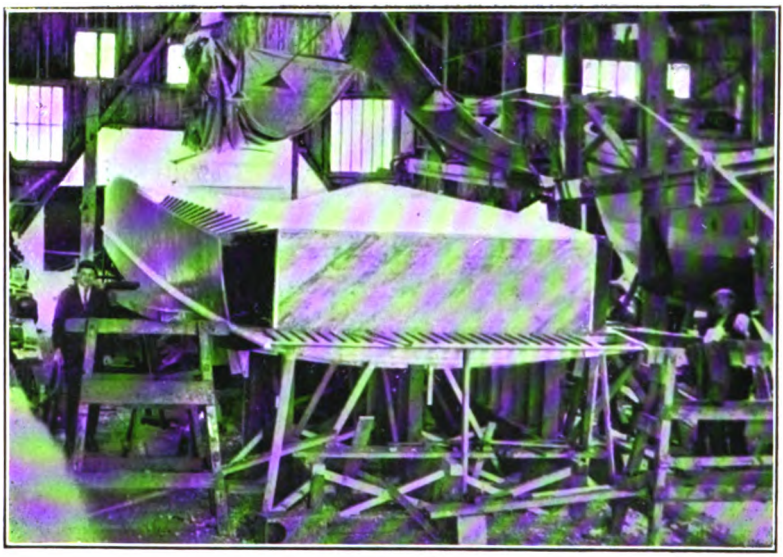

Fig. 7.

Fig 8.

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only. Sleds are by no means the fastest of motor boats, as they have never come up to anything like the "Maple Leaf VII," which was designed and built some years ago by Messrs. S. E. Saunders, Ltd., of Cowes; she attained a speed of over 80 m.p.h. Again, sleds are very much in the minority in the high-speed motor boat world. The inverted-vee or sled type of boat is not the easiest to drive; it comes midway between an ordinary vee-bottom and a step-bottom boat. That is to say, with three boats of the same displacement, fitted with identical motors, a mono-step boat will be considerably faster than an inverted-vee type, which in turn will be faster than an ordinary vee-bottom boat.

I know of one comparison where model experiments gave the following results:—

Mono step - - -	34	knots,
Inverted vee - - -	27·5	,,
Ordinary vee - - -	24·5	,,

all having the same displacement and motors of the same b.h.p.

Mr. Perring is correct in stating that the structural arrangement of hulls for fast motor-boats requires more than ordinary consideration. Naval architects require to specialise if they wish to excel in high-speed craft design, especially when high speeds have to be guaranteed with engines of moderate power. I do not agree with the statement on page 729 that all fast boats have their maximum beam aft, as I know of many high-speed hydroplanes in which the waterline tapers away at the transome end, but, of course, these are purely racing boats.

I do not consider the speed of 30 miles per hour a very good performance for the power installed in Mr. Perring's 22-foot sled. Last year I designed and built a boat only 18 feet in length, with a 1½-litre engine, which attained a speed of over 40 miles per hour. This little boat was steered by Miss

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Mr. David Nicolson.
Carstairs, and won most races of her class in this country and on the Continent.

With regard to Mr. Perring's remarks about building boats bottom uppermost, this is quite the usual practice in British, French, and American yards for the construction of racing and similar craft, as it is of considerable advantage to the workman during construction. He does not mention the thickness of the bottom planking, sides, or deck of his sleds. I believe scantlings for these parts could have been reduced if he had used "consuta," thus saving in weight, a most important factor. Some years ago Messrs. S. E. Saunders built several sleds, their dimensions being 24 feet in length by 6 feet in breadth, in which the bottom planking was $\frac{7}{16}$-inch mahogany consuta, and the side planks, deck, and bulkheads of $\frac{3}{8}$-inch consuta. If Mr. Perring had used consuta he could have put on each side in one piece, each half of the bottom in one piece, and the deck in complete sections, likewise the bulkheads. This method of construction is obviously much cheaper, as the time taken to work an ordinary diagonal plank and riveted system is very much longer.

I hope that a few words on consuta will not be out of place, but for the benefit of those who have not heard of the material I should like to state that it is a super-plywood, built up of small planks not more than 6 inches wide, the laminæ being cemented together, then put under a pressure of about 80 lbs. per square inch, and the whole stitched through in parallel rows, each stitch being locked. The material is made in thicknesses from $\frac{1}{32}$ to $\frac{7}{8}$ inch, and in two, three, or more plys. The grain of the laminæ is laid in the directions most suitable for the particular purpose for which it is to be used. For boats or sleds the layers or plys are usually laid with the grain running diagonally at 45 degrees to each other. All the edges are end grain wood, so that when the material is fitted close up to a chine, gunwale, rabbet of keel, etc., there is no tendency to expansion or contraction; thus no leakage can

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take place. Consuta can be made in almost any size; up to the present it has been manufactured in pieces up to 50 feet long by 8 feet wide.

Mr. Perring seems to be of the opinion that he attained a great speed with his 50-foot sled, installed with two Liberty motors with a total of 800 horse-power, giving on trial 40 knots. On this subject it is sufficient for me to state that last year a speed of over 43 knots was attained on trial with the "Oma," and her horse-power was just about one-half that of the sled.

The actual particulars of the "Oma" are as follows:—

Length - - -	30 feet.
Beam - - -	8 feet.
Displacement - -	3·65 tons.
B.H.P. - - -	450.
Engine - - -	Single "Lion."

This year the same boat, carrying 10 people, attained a speed of 50 miles per hour. The chief advantage of the sled form appears to be its good stability, but I claim that with the same horse-power and the same displacement I can obtain higher speeds with hydroplanes having one or more steps, and ample stability for all purposes.

On page 736 Mr. Perring refers to sled boats as being adapted for slow-speed work in canals, but I cannot see that they possess any advantage whatever for this kind of work over the ordinary flat-bottom tunnel-stern launches, which for many years have been built for use in shallow waters.

Referring again to high-speed boats, it may be of interest to note that the ratio of displacement in lbs. to b.h.p. for mono-step hydroplanes ranges from 20 up to 50 lbs. per horse-power, but unfortunately Mr. Perring gives no data in his paper, and I am, therefore, unable to make any comparisons. Furthermore, I should like to point out that the cost of construction of any inverted-vee or sled hull is considerably greater than the cost of a stepped hydroplane hull.

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Mr. James Anderson.

Mr. JAMES ANDERSON (Member): During the war I discussed the question of vee-bottom boats with several officers, and in 1919, when I returned from active service, the boat-building company with which I was associated considered what the probable development of this type would be. It was recognised that it had several advantages over the round-bottom type, which was commonly adopted in this country, and I induced a friend to build a boat on the vee-bottom principle. It was successful, and eventually the fourth one was placed on show at the Exhibition in the Kelvin Hall, Glasgow, in 1920, with the result that several were built on the Clyde. An English company also put forward a proposition for high-speed vee-bottom boats, and two or three of them were built for Clyde owners.

Coming now to the type detailed by Mr. Perring, namely, the sea sled, personally I do not like it. My reason is that many years ago a cross-channel steamer of the double-hull type was built for service between Dover and Calais, and owing to the contraction of the space between the hulls the water displaced from the bow piled up amidships, rendering the vessel unsatisfactory from a speed point of view. The form of the sea sled virtually amounts to two hulls, made from one hull cut in two longitudinally, with the outsides turned to the inside. In a moderately calm sea, such as a loch or a river, where the seas are short and there is no great weight in them, I think this type of boat would be a feasible proposition. In fact, it might be quite a suitable boat for using on Loch Long between Arrochar and, say, Loch Goil, but I guarantee that no one would venture to take a sea sled in a sou'-wester from Dunoon to Gourock. The metacentric height of the sea sled is about twice that of a vee-bottom boat, or the ordinary round-bottom boat. What does that mean? Simply that the arm for recovery is greater, and that the boat will be thrown up to windward. In a beam sea a boat should not have too great a metacentric height; it should work easily,

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Mr. James Anderson.

and that is my great objection to the sea sled. It may be all very well for punching dead to windward, but I do not think it could carry on in a beam sea.

There are no lines illustrating Mr. Perring's hull, and, therefore, it is impossible to discuss it scientifically. There is only a midship section from which I conclude that the design is weak. I base that statement upon the section which Mr. Perring gives. It will be noticed that it is very strongly strutted. Why? Because when the bow is pounding into a sea, the combined action of all the forces tends to burst asunder the two sides of the vessel, and the inverted vee, which causes this bursting stress, must be very strongly supported. I have no objection to a vee-bottom boat in which the vee takes the form of an ordinary hull, and I think for certain purposes it fulfils a very useful function.

On page 732 it is stated that starting, stopping, regulating, and so on are done in a manner more or less similar to that of a motor car. Now to marine engineers and seamen can there be anything more disappointing or more objectionable than a boat controlled like a motor car? The thing is absurd. I have had some experience of steering high-speed craft, but I do not like the motor-car steering method. An inclined steering wheel may be the most suitable in a motor car, but I cannot see that it is the best for marine purposes; it is wrong dynamically.

Mr. Perring refers to this type of boat as a cruiser. I disagree with him. It is not a cruiser. It cannot go to sea, and it has no sleeping accommodation. It might be more correct to call it a day cruiser.

Mr. C. R. H. Bonn (Associate Member): As the sea sled has been compared with the motor car in the matter of steering, I think it would be interesting to carry the comparison still further. What, for instance, would be the horse-power for a motor car of the same speed and weight as the

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Mr. C. R. H. Bonn.

sea sled? On the basis of equal weight and a speed of 40 miles per hour, the horse-power of the sea sled would appear to be many times that of the motor car, and taking the wind resistance to be approximately the same, the extra power for the sea sled must be lost in wave-making resistance.

If the air entrapped at the fore part when the sea sled is running does reduce wave-making and surface friction, could the principle of creating an air film not be extended to the sides? A marine superintendent told me that he frequently had patents sent to him, and one of these, which he considered very foolish, was a frame of perforated tubes, supplied with pressure air, to be carried in front of the bow of a vessel, the idea being that the escaping air would glide along the sides of the ship and help to reduce skin friction. There may be something in the idea as applied to the fast sea sled, but instead of the frame of perforated tubes, it might be preferable to have the perforations supplying the pressure air in the sides of the boat itself. It has been demonstrated that wave motion may be destroyed by liberating air. Some time ago an American firm enclosed an area of a New England state bay by a perforated tube laid on the bottom. This tube was supplied with pressure air from a compressor on shore. The escaping air, in travelling to the surface, destroyed the Atlantic rollers, and the water inshore of the pipe was comparatively smooth in consequence. This is perhaps away from the point, because it is one thing to prevent wave-making and quite another to destroy waves once created.

As it seems impossible to eliminate wave- and eddy-making, no matter what form of hull is employed, the only hope of reaching higher propulsion efficiencies appears to lie in utilising the wave energy.

Mr. J. A. Miller (Associate Member): If there has been no great amount of discussion, it is only because in this part of the country we are not very well acquainted with speed

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Mr. J. A. Miller.

boats, as such. We are more familiar with small motor-boats of the sturdy Scotch fishing type—cruisers in the fullest sense of the word—in which one may eat, sleep, and go anywhere. In seeking information rather than attempting to criticise the design of the sea sled, it seems to me that its stability, compared with that of a vee-bottom boat, should resemble that of, say, a man sitting astride a rope contrasted with one in a sling. With the inverted-vee construction, would there not be a tendency to roll over; more so, perhaps than if the sides were to overhang instead of being sheer? Mr. Anderson objects to the controls being "planned to approximate as closely as possible to those of a motor car." One can fully appreciate that a sailor must regard with something of aversion anything unseamanlike—in this case I might say land-like—about his craft, but I agree that it must be very helpful in controlling a boat of this type to be able to make fullest use of habits already acquired on land in driving a motor car. Concentration and accessibility of controls are important in a speed boat, and it would be a pity to sacrifice anything of efficiency for the mere sake of being different.

Mr. D. L. Evans, B.Sc.: Mr. Perring's remarks on the sea sled are most interesting to anyone who has been connected with high-speed motor boats, and if he could give some comparative figures between the sea sled and the more common type of stepped hydroplane they would prove of great value. During the war the sea sled was introduced into this country from America in the shape of a quadruple-screw boat, which was by no means popular in the Service, largely on account of the difficulty of controlling the four engines with which it was fitted. This may seem to be purely a mechanical disadvantage, but the real reason for providing so much power was the inefficiency of such a form.

Messrs. Thornycroft at that time were building 40-foot coastal motor boats of the single-step hydroplane type, and

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Mr. D. L. Evans, B.Sc.

they constructed a sea sled of the same dimensions and with similar machinery. If my memory is correct, the best speed performance of this boat was 27 knots, as against 33 knots with their own form. At these high speeds it can readily be appreciated that a Thornycroft type of skimmer at 27 knots would be using very much less power than a sea sled at the same speed. The chief reasons for the lower efficiency of the sea sled are, I think, (1) that the cleft of the sea sled at the forward end collects water, whereas with the other type the water is thrown clear; and (2) the increased air resistance of the sea sled form. As regards seaworthiness, there was little to choose between the two types, the coastal motor boats being splendid sea boats, the only advantage shown by the sea sled being the absence of spray forward, which made them less easily spotted than the coastal motor boats.

I do not think there is any less vibration with surface propellers than with the under-water type. Any reduction due to lessening the rake of the shafting is more than counterbalanced by the increased vibration set up by the blades entering the water. Large slow-running propellers are more efficient than small fast-running ones for surface propellers, and, with the high-speed engines fitted in this type of craft, gearing, with the resulting additional weight and complication, must be introduced to obtain the same efficiency.

Sir JOHN E. THORNYCROFT, K.B.E.: On reading through Mr. Perring's paper I find that it does not deal with high-speed boats generally, so it would seem that the title should have been rather more restricted. It refers almost entirely to the particular design known as the sea sled, which was produced in America by Mr. Hickman a year or so before the war. When it was introduced a good deal was said about the superior sea-going qualities of the hollow vee-bottom type, and in the early days of the war when my firm were building the small motor torpedo boats, known as C.M.B.'s, it was sug-

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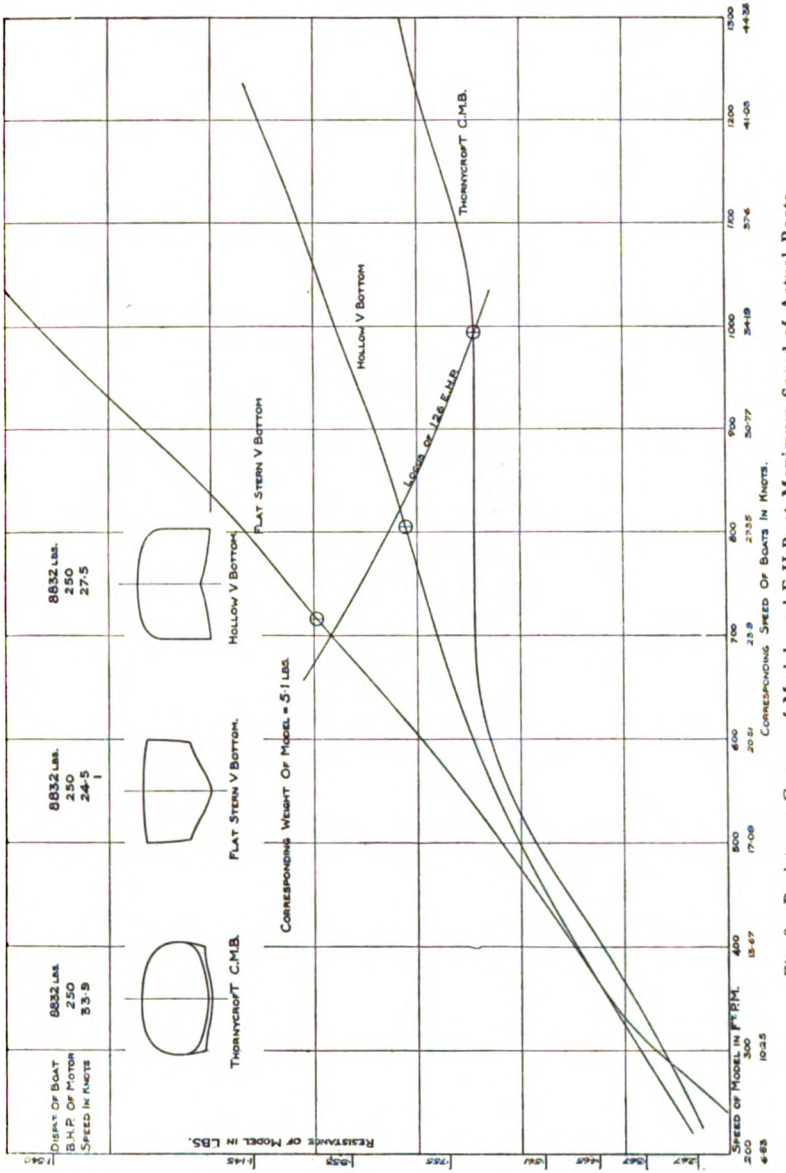

Fig. 9.—Resistance Curves of Models and E.H.P. at Maximum Speed of Actual Boats.

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Sir John E. Thornycroft, K.B.E.

gested that the sea sled form of hull might have advantages. The Admiralty obtained one from America, and another was built by my firm to a similar design but of different dimensions. In practice it was found that the single-step form was not only considerably faster, but in every way more suitable to carry a torpedo. To settle the relative efficiency of different forms of hull, experiments were made not only with models but with actual boats, both the ordinary and semi-immersed propellers being tried. Fig. 9, giving the results of the trials, may be of interest, as it definitely shows that the hollow-bottom form has a greater resistance than the single-step form.

A great deal of time and money has been spent in America on building boats to obtain the highest possible speeds, and it will be found, on investigating their designs, that they have all come to the single-step form which was developed and patented by Sir John I. Thornycroft 17 or 18 years ago. The sea sled undoubtedly rides extremely smoothly, and has the characteristic, which may be an advantage in certain cases, of not throwing out any spray sideways.

Prof. Percy A. Hillhouse, D.Sc. (Vice-President): We are much indebted to Mr. Perring for his paper, which, though brief, brings to our notice a type of high-speed boat of which comparatively little is known in this country. As in the case of all fast vessels, the vital requirements appear to be minimum weight and maximum power; but length in these particular craft is of secondary importance. The speed-length ratio, if calculated from the actual waterline length when in running trim, and the Admiralty coefficient, must both be extraordinarily high. The loads to be carried, other than those of hull and machinery, must have an important influence on the behaviour of the vessel, and I imagine that great consideration must be given to the number of the crew and their individual weights as well as to the positions they are to

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occupy. It would be interesting to know just how speed and trim are affected by total load,

"Inverted vee" is rather an awkward name. Would not "W" be more descriptive?

Mr. Perring would add to the value of his paper if he could give a diagram showing the lines of action of the water resistance, propeller thrust, and weight, when the vessel is at full speed, and the appropriate triangle of forces showing how equilibrium is maintained.

In "International Marine Engineering," August, 1918, Mr. T. A. Gamon gives the lines and resistance curves for several vee-shaped models. At 4·0 speed-length ratio, model No. 1, 3 feet by 0·4475 feet with a displacement of 4·29 lbs., has a resistance of ·9 lb. (surface friction ·675, and wave-making ·225). This corresponds to a speed of 28·3 knots for a similar vessel 50 feet by 7·45 feet and 8·85 tons displacement, with about 250 e.h.p. Mr. Perring's vessel is 50 feet by 11·5 feet and 8·75 tons displacement, and attains a speed of 40 knots—a much better performance.

Mr. Perring: I have to thank the various speakers who have taken part in the discussion of my paper.

Mr. Nicolson's remarks upon the use of consuta plywood are interesting; as a matter of fact, the sides, decks, and bulkheads of the large sled were of consuta construction. I do not consider consuta construction altogether suitable for bottom planking where there may be appreciable change of curvature; for those parts I believe Messrs. Saunders sometimes mould the consuta to shape, and this practice may obviate some of the troubles that might otherwise arise. As Mr. Nicolson points out, the sled type is not the most economical form from a power point of view, and for purely racing craft some other type should be adopted.

It is not easy to compare the results of the sled with those

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Mr. W. G. A. Perring.

given for the "Oma"; but if $\frac{\Delta^{\frac{2}{3}} V^3}{\text{b.h.p.}}$ values of the two boats are taken as a basis, then this value for the "Oma" is about 420, and for the sea sled 390. The sled on trials was only developing about 700 b.h.p. Compared on the displacement per horse-power basis, the figure for "Oma" is 18·2 lbs., and for the sled 28 lbs. per b.h.p., but it must be remembered that the speed of the "Oma" is about three knots faster than that of the sled.

I can assure Mr. Anderson that sleds behave quite well and are not uncomfortable or "wet" in seas that would certainly trouble the ordinary vee type of hull. I should like to point out that a section, well strutted to resist straining actions, does not indicate weakness; it is obvious what are the strains most likely to deform the hull, and, of course, the necessary members have been built into the form to resist these forces.

To the speakers who dislike the idea of motor car control for motor boats, I may point out that such an arrangement is not a necessary feature of the craft. There are arguments for and against the arrangement, and ultimately any differentiation becomes largely a matter of taste.

I agree with the superintendent of Mr. Bonn's acquaintance regarding the futility of reducing skin friction by schemes based on lubrication of the surface. For any of these schemes to achieve their object, it is necessary to produce a layer of air completely enveloping the form and separating it from the water; in practice the air breaks into large bubbles and leaves the form altogether.

I thank Sir John Thornycroft and Mr. Evans for their remarks, and agree that the sled type of hull is slightly more expensive in power than the C.M.B. type, but whether this is offset by its general behaviour and "dryness" is perhaps a very debatable point.

Prof. Hillhouse, in pointing out the important influence the "load" carried, and its distribution, has upon the behaviour

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of the vessel, stresses a very important point. Some experiments with a small sled showed as much as a knot improvement in speed by a redistribution of the passengers carried, the actual speed being around about 20 knots. With the larger sleds, however, the position of passengers and crew, although important, is not so critical. His suggestion to name the type "W" boats rather than "inverted vee" is quite a good one.

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STUDENTS' SECTION.

Abstracts of Papers Read.

NOTES ON PUMPING.

By J. A. McCash, B.Sc.,
Student of the Institution.

13th November, 1925.

The intensive search for economy in the operation of the main engines of land and marine installations has lately been extended to include the auxiliary machinery. The steam and power requirements of the latter are in the region of 25 per cent. of the total consumption, a figure out of all proportion to the work done. This is due to improved design in the main engines, and a relative disregard of the performance of the smaller units.

In an ordinary marine installation, under the heading of auxiliary machinery, are included feed, air and circulating, ballast, bilge, and lubricating oil pumps. Although the power required to drive these pumps is, as a rule, small, the fuel consumption is comparatively high.

Direct-acting pumps, both single and duplex, take full steam for practically the whole stroke, and consequently cannot be expected to give a high thermal efficiency. In marine practice the auxiliaries exhaust at a pressure above atmospheric, the exhaust being used for feed-heating, thus obviating the use of a condenser.

To reduce the working cost in steam pumps, much can be

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accomplished by scientific spacing of the ports in the steam chest and cylinder, careful selection of packing, care in the packing and tightening up of the glands, cleading of the cylinder and steam leads, and a suitable disposition of the pumps in the engine-room.

To operate efficiently a pump should be designed for its particular duty, as owing to the varied uses of pumps no general formulæ for their working can be postulated.

The designer should be given information regarding the nature of the liquid to be dealt with and the maximum capacity desirable. A sketch should then be made showing the position of the pump relative to the sump and the boiler valve, and also the bends and valves in the suction and discharge lines if these are already in position. In stating the nature of the driving power, if for steam or compressed air, the average working pressure and the distance from point of supply should be given; if for electricity, the voltage and current.

An important factor in their operation, particularly in small pumps, is the design of the suction piping. The height to which a pump will draw is the difference between the head corresponding to atmospheric pressure, and the sum of the heads represented by the height to the end of the piston stroke from water level, the frictional loss in the suction pipe, and the loss due to inertia of the water.

To reduce friction and prevent air locking, the suction pipe should be as short and straight as possible; it should fall continuously from the pump to the supply well, and be free from air leaks.

The rate of discharge of a pump is variable, particularly so in crank-driven pumps where for uniform speed of the crank, and assuming water to be incompressible, and also that the water follows the piston, the discharge is in the nature of a simple harmonic motion. It follows, therefore, that there is a variation in pressure, due to change of momentum.

Owing to this variation of pressure, the forces set up in the

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suction and discharge pipes must be allowed for. Further, since the water does not always follow the plunger, as assumed above, separation of the water column may take place, mainly on the suction side, with consequent water-hammer.

To reduce the variation of the velocity in the pump mains, and to make the inertia forces smaller, air vessels are introduced on either, or both, the suction and discharge sides of the pump. The object of the air chamber is attained when the pressure variation in the mains is slight, while the water which is accelerated is only that which lies between the pump and the air chamber. This permits a higher speed of pumping.

The suction air vessel, which is used when the tail pipe is long, may be considered to receive water at a steady rate, but to give to the pump an amount which varies for different crank positions. It is usual to allow for a capacity of from four to five times the pump capacity per barrel for single-acting, and two-thirds capacity for double-acting, pumps.

The discharge air vessel is used with long delivery pipes and high velocity of flow, except in cases where the presence of air, owing to its tendency to produce corrosion, is undesirable, as in feed pumps, though air vessels *are* used in feed pumps. Air vessels when fitted should be so placed that the water flows upwards into the vessel and out at a somewhat higher level, as in this way the air becomes a better shock absorber than in the case where the flow is merely across the inlet. To remove water shock, air is sometimes introduced into the pump between the suction and discharge valves. This, of course, cannot be done if the water flows into the barrel by gravity. Under these conditions it becomes necessary to throttle the pump at the inlet, which can be done conveniently by means of a gasket. Other than for its cushioning effect, however, air is undesirable. As the amount of air in the barrel diminishes, the ability of the pump to lift water is increased. If there were no air in the barrel,

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the amount of pump clearance, which in practice is always present, would not affect the pump efficiency at all.

The difference between the volume swept through by the plunger and the actual discharge, is termed the slip. Slip is due to leakage past the piston and the slow closing of the suction valves on the delivery stroke. Careful experiments on various pumps at full speed show that in a new pump with clean valves, and an air-tight suction pipe with less than 15 feet lift, the actual delivery is only from two to five per cent. less than the plunger displacement. Slip will increase with wear, and for a good average pump probably ten per cent. is a fair allowance to cover slip, valve leakage, short-stroking, etc.

In the case of pumps with a long suction pipe and a low delivery pressure, the pressure due to the inertia of the column of water in the suction pipe may be large compared to the pressure on the outside of the delivery valve, especially if the speed be great. This may cause the delivery valve to open before the end of the suction stroke, with the gratifying result that a greater volume of water is delivered than that swept through by the plunger. This makes the theoretical discharge less than the actual; the slip then becomes negative, and the coefficient of discharge is greater than unity.

To reduce slip and inertia losses a long stroke is desirable, for the reason that the inertia to be overcome is thereby reduced and the friction losses in the passages become less, due to fewer reversals for the same piston speed. The wear of the working parts is also reduced, and the pump has a better chance of completely filling itself at each stroke. In horizontal pumps, the available floor space frequently determines the length of stroke. When a short stroke is compulsory, the effect is to increase the diameter of the plunger, with a corresponding increase in weight of the cylinder, piston rod, crosshead, etc.

The several kinds of pumps in general use for marine work are in the main steam driven, and of the double-acting

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simplex or duplex type. Desirable features in design include strength and simplicity of working parts, long stroke, positive action in the valve gear, and continuity of discharge, while capability for steady running at a fair variation of steam and discharge pressure is essential. A pump should also be capable of starting at any position of the stroke.

Recently there has been an increasing tendency to use feed pumps of the simplex type for boiler feed. The advantages claimed for these pumps are:—

1. Economy in space occupied.
2. They can be made with less steam-port area than the duplex pump, and can be run slower than a geared pump.
3. They can be conveniently compounded for use with high pressure.
4. When used in pairs, common connection pipes can be used for feed, or for general service.

In testing pumps for watertightness and strength, the discharge valve and, if present, the relief valve are shut down, and the steam end adjusted to give a pressure of about 250 lbs. per square inch at the water end. Joints should remain tight at this pressure, and the pump should creep slowly and uniformly, except near the dead centres when the valves are closing. If the pump moves more quickly than a moderate leakage would indicate, either the rings or the suction valves are not tight. If the rings are tight, the suction valves cannot be lying dead on their seats, or the latter have been damaged during fitting, allowing the water to get beneath the valves, and causing them to lift. If the pump is found correct, the relief valve can now be suitably adjusted to discharge at about 10 lbs. per square inch above the working pressure. The cast-iron air vessel for a high-pressure pump should be tested at about 400 lbs. per square inch before connecting up.

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LIGHT INTERNAL-COMBUSTION ENGINES.

By W. Park Kirkwood, B.Sc.,
Student of the Institution.

15th January, 1926.

In the light internal-combustion engine a more or less volatile liquid is almost invariably used as a fuel, although it will run on practically any combustible gas. The reason for this is that the development of the light engine has been solely due to the need for a small, self-contained power unit for the propulsion of road vehicles and aircraft. It is the intention in this paper to consider the engine simply as a means of converting heat energy into work, and to discuss only such mechanical details as enter directly into this problem. For this purpose, it is convenient to follow the path of the working fluid along the lines of maximum efficiency.

For a clear perception of this change from heat energy to work, it is essential to keep in mind throughout the fundamental principles for the perfect utilisation of the force of explosion, first laid down by Beau de Rochas in 1862, which state that there must be—

1. The largest possible cylinder volume contained by a minimum amount of surface.
2. The highest possible speed of working.
3. The maximum expansion.
4. The maximum pressure at the beginning of the expansion.

With regard to the first condition, it is obvious that the ideal combustion space is spherical, since a sphere gives the

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maximum volume for the minimum surface area. The object of having the surface area as small as possible is, of course, to reduce the heat loss to the cylinder walls, which is always considerable, and may rise to over 30 per cent. of the total heat supplied. Unfortunately practical considerations usually make this ideal impossible of attainment, although some engines approach fairly closely to it.

The second condition is partly due to the fact that the heat loss to the cylinder walls is proportional to the time taken to perform a single cycle. Since the heat flow through the walls from a high temperature to a lower one is fixed by the material of the walls and the difference in temperature between the two sides, it is evident that in any engine, while the total heat input is increased if the speed is increased, the loss to the cooling water increases more slowly, that is, the percentage loss to the cooling water is less. The other fact is that the power obtainable from any engine is theoretically proportional to its speed. Again, this condition is controlled by practical considerations, for the stresses on the reciprocating parts due to inertia, increase as the square of the speed, so that speed is limited by the materials at present in use. To try to strengthen up a reciprocating part by the addition of more metal is useless, as the extra weight increases the inertia loads, and so defeats its own object. The only line along which advance can be made is that of increasing the strength-weight ratio of the materials used. In this connection, it is interesting to compare the so-called specific strength of the various metals used for pistons. The following figures are for the metal in the cast state, and are obtained by dividing the maximum stress by the specific gravity:—

Cast-iron - - -	1·9 to 2·3
Aluminium alloys -	3·1 ,, 3·8
Magnesium alloys -	3·6 ,, 6·2
Y alloy (Cu.Ni.Mg.) -	4·8 ,, 8·2 (heat treated).

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These figures are for ordinary temperatures, but the moving parts of an engine are at a high temperature, the piston especially, and a more equitable basis of comparison is the specific strength at 250 degrees C., at which we have:—

Cast-iron - - -	1·4 to 1·7
Aluminium alloys -	1·4 ,, 3·3
Magnesium alloys -	3·1 ,, 3·2
Y alloy - - -	6·2

It is thus seen that even at fairly high temperatures the light alloys possess a considerable advantage over the once universal cast-iron.

For connecting rods, light alloys, usually in the forged state, of late years have been used with great success, particularly duralumin, which is a complex alloy of aluminium, copper, magnesium, silicon, and manganese. By the use of these light alloys, it has been possible to increase the speed of engines to such an extent that many are running to-day at 4,000 r.p.m. continuously.

After having overcome, partially at any rate, the hindrance to high speed by the use of light reciprocating parts, the engineer is faced with the difficulty of introducing the working charge of vapour and air into the cylinder in an extremely short time. The actual time that the inlet valve is open rarely exceeds 200 degrees of crankshaft travel, which means that at 4,000 r.p.m. the total time for getting the charge into the cylinder is about $\frac{1}{120}$ of a second. The charge has to be accelerated from rest, passed through the valve at a mean velocity of 200 feet per second, which is over 136 miles per hour, and brought to rest again all in this brief period of time.

At this high speed it is impossible to get the same weight of charge into the cylinder as at slower speeds. Consequently, it is found in practice that the power of an engine is not proportional to its speed, but begins to fall away after a certain

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speed has been reached, after which any increase in speed is accompanied by a decrease in power, until finally the engine only develops sufficient to keep itself going, and the application of any external load will cause it to stop. The difficulty in getting sufficient weight of the working charge into the cylinder may also be caused by ascending to a great altitude, where the rarified atmosphere causes the same loss as high speed at normal altitude. This is most pronounced in aircraft where the lack of power when flying high is a great handicap, but with motors the effect is not so noticeable.

This difficulty is overcome by the use of a supercharger, which is really a pump, to force the charge into the cylinder at a pressure in excess of atmospheric. Superchargers have been used to a limited extent for some time on aircraft, and lately on racing cars, where the high speed of rotation of the engines has induced their designers to find a means of preventing the power from falling away until a speed of 5,000 r.p.m. or even 6,000 r p.m. is reached.

Although primarily intended to prevent loss of power at high speeds, the supercharger is also able to increase the power of an engine at quite low speeds by increasing each charge above the normal.

To ordinary users of light internal-combustion engines, to whom high speed of rotation does not often commend itself on the score of wear, this increase of power at comparatively low speeds is undoubtedly the most interesting feature of the supercharger, as it enables the engine to be reduced in size, while the same output is maintained.

The third condition, maximum expansion, is one which does not admit of any variation, as all engines must exhaust to the atmosphere. A condenser for creating a vacuum is, of course, impossible, as the products of combustion are gaseous, and the extra power required to drive a vacuum pump would be greater than the increase obtainable from the engine so fitted.

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The fourth condition, maximum pressure at the beginning of the expansion stroke, is probably the most important of all, for on this hinges the power developed by the engine, irrespective of speed. The formula for horse-power,

$$\text{I.H.P.} = \frac{\text{P} \cdot \text{L} \cdot \text{A} \cdot \text{N}}{33{,}000},$$

where P = mean effective pressure,
L = length of stroke,
A = area of piston,
N = No. of explosions,

shows at once that, the engine and the speed of rotation being fixed, the only way of varying the power is by changing P, the mean effective pressure. Now the mean effective pressure is proportional to the maximum pressure at the beginning of the expansion stroke, which, in turn, is proportional to the compression pressure or compression ratio. This means that for maximum power the compression ratio must be as high as possible.

In practically all light internal-combustion engines, the explosive mixture is compressed in the cylinder, as opposed to the Diesel or solid-injection engines, which compress pure air, and the limiting figure for the compression ratio is reached when the mixture ignites spontaneously while being compressed. This point is different with different fuels. The four basic fuels used at the present time in order of amount consumed are petrol, paraffin, benzol, and alcohol. The highest useful compression ratios that may be used with these fuels in their average condition are:—

Petrol - -	5·2 to 1
Paraffin - -	4·2 ,, 1
Benzol - -	7 ,, 1
Alcohol - -	8 ,, 1

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If these ratios are exceeded, there is a distinct danger of the charge preigniting, with possible damage to the engine.

The value of benzol on high-compression engines has long been known and made use of, while alcohol is now advancing in popularity, especially on the Continent, where petrol is dear, and alcohol can be manufactured cheaply from beet, potatoes, etc. A point to be remembered in comparing petrol or benzol with alcohol is that the calorific value of the former is about 19,000 B.Th.U's. per lb., while the latter is only 11,000 B.Th.U's. per lb., which means that nearly twice as much alcohol has to be consumed to produce the same power as petrol. Therefore alcohol, to be a practical proposition, must be obtainable at about half the price of petrol. This is a point often completely overlooked when the wider use of alcohol is being advocated. For racing, of course, where price does not come into the question at all, the great value of alcohol is that it enables engines to be run at a much higher compression than would be possible with petrol, with the resulting increase in power. Curiously, however, the power obtained from the four fuels is approximately the same at the same compression ratio except paraffin, which is slightly lower. The reason why alcohol is able to give the same power as petrol, in spite of its lower calorific value, is that its latent heat is much greater, thus allowing a much denser charge to be drawn into the cylinder.

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THE "JAMES WATT" DINNER.

THE annual "James Watt" Dinner was held in the Banqueting Hall of the Grosvenor Restaurant, Glasgow, on Friday, 20th November, 1925. Mr. A. J. Campbell, President of the Institution, occupied the chair, and amongst those present were The Right Hon. The Earl of Cassillis, D.L., J.P.; The Right Hon. Lord Lamington, G.C.M.G., G.C.I.E., D.L., J.P.; Sir William H. Raeburn, Bt.; Vice-Admiral Sir Walter H. Cowan, Bt., K.C.B., D.S.O., M.V.O.; Sir Thomas Paxton, Bt., LL.D.; Sir Thomas Bell, K.B.E.; Mr. W. J. Berry, C.B., Director of Naval Construction; Mr. Harold E. Yarrow, C.B.E., Past President; Capt. Roberto Guedes de Carvalho, B.N.; Sir John Hunter, K.B.E.; Sir Thomas F. Wilson, K.B.E., Clerk of the Peace; Lord Dean of Guild, Dr. R. T. Moore; Sir Alexander Kennedy; Sir Alexander Richardson; Sir John S. Samuel, K.B.E.; Eng.-Rear-Admiral W. J. Anstey, C.B., J.P.; Eng.-Capt. W. Onyon, M.V.O., R.N., Member of Council; Mr. Robert Traill, Member of Council; Mr. Val. Beardmore Stewart, C.B.E.; Mr. John Craig, C.B.E., Member of Council; Mr. C. R. Lang, C.B.E.; Mr. Sam Mavor; Mr. William Gordon; Eng.-Com. R. J. Brown, D.S.O., R.N.; Mr. A. Scott Younger, B.Sc.; Mr. W. W. Marriner, Member of Council; Lieut. R. W. K. Twinberrow, R.N.; Mr. J. Foster King, C.B.E.; Lieut.-Col. T. K. Gardner, Member of Council; Prof. Magnus Maclean, D.Sc., LL.D., J.P., President, The Institution of Electrical Engineers, Scottish Centre; Prof. J. D. Cormack, C.M.G., C.B.E., D.Sc., Member of Council; Provost John Garrick, Dumbarton; Dr. James Montgomerie; Dr. Edward Mackay, President, Greenock Philosophical Society; Mr. S. J. Pigott, Member of Council; Mr. W. Millar, O.B.E.;

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Mr. John M. Gilchrist, O.B.E.; Eng.-Capt. J. H. Watson, R.N.; Mr. Wallace C. Fairweather; Mr. A. Wedgwood, Member of Council; Mr. E. W. Fraser Smith, M.A., Secretary North-East Coast Institution of Engineers and Shipbuilders; Mr. W. Alexander; Capt. S. R. Aitken, Member of Council; and Capt. W. J. Saunders.

The Croupiers were Mr. James Brown, C.B.E.; Mr. Maurice E. Denny, C.B.E., B.Sc.; Mr. N. O. Fulton; and Prof. Percy A. Hillhouse, D.Sc.

After the guests had assembled, the news of the death of the Queen-Dowager was received. As many were present from a distance, it was considered inadvisable to abandon the function, but the musical portion of the programme, which was to have been the feature of the evening, was cancelled.

The CHAIRMAN, submitting the toast of "The King," said:—My Lords and Gentlemen, I greatly regret to say that since sitting down to dinner we have received the sad news of the death of Queen Alexandra. I am sure you will agree with me that this is a national loss. She was the beloved Consort of the illustrious King Edward, and was one of the best of women. Under these circumstances, you will agree that the toast I am about to submit ought to be drunk in silence—the toast of "His Majesty the King and the Royal Family"—with full sympathy in the very trying circumstances which His Majesty is passing through at this moment.

After the toast, an adjournment was made for half-an-hour. On the company reassembling,

The CHAIRMAN said:—The toast which I have the honour now to propose is that of "The Immortal Memory of James Watt," which, in accordance with our usual custom, will be drunk in silence.

Mr. HAROLD E. YARROW, C.B.E., in proposing "Our Guests," said that when he was asked to propose this toast he was also asked to remember two things. One was to be brief, and the other was to make his voice heard throughout

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the room. In other words, he was asked to be a kind of loud speaker. He felt it a great privilege to be entrusted with this toast, more especially as there was a number of distinguished guests present. Besides representatives of the House of Lords, there were representatives of the Navy in a distinguished naval officer, and the Director of Naval Construction. The lamentable loss of submarine M1 reminded them, if any reminder were necessary, of the work and risks connected with naval duties, and their sympathy went out to the relatives of those brave men who had lost their lives in the service of their country. The Navy was always in action, both in war and in time of peace, and it was due to the high standard of professional efficiency at the Admiralty and in the Navy that these accidents were not more common. Mr. Berry was confronted with a most difficult task—he had to put as much into a warship as possible, and, in addition, he was limited to the restrictions of the Washington Conference—and the country might be well satisfied that they had him as the head of naval construction. He might perhaps be allowed to commend to Mr. Berry's attention the necessity—speaking, of course, quite disinterestedly—of increasing the programme of torpedo-boat destroyers. He also welcomed on behalf of the Institution a distinguished naval officer from one of their allies—Captain Roberto Guedes de Carvalho, the Brazilian Naval Attache.

He regretted the absence of the Right Hon. the Lord Provost of Glasgow. His Lordship was to have been present, but he was engaged at Westminster on the question of extending the city boundaries, with which all of them were not in entire sympathy. The Lord Provost of Edinburgh was also to have been present. Perhaps he was also looking around, even in that part of the country, to see whether he could not annex something. They had with them the chairman of the Clyde Trust, Sir William Raeburn. Engineers and shipbuilders were dependent on the efficiency of the River Clyde, and the Clyde Trust was also dependent on the efficiency of engineers and

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shipbuilders. He did not think anyone could doubt the high efficiency wth which the Clyde Trust was managed, although he did not think the river had been of much use to anyone during the past few days of fog. For that they could not blame Sir William Raeburn. They had also with them Dr. R. T. Moore, the Lord Dean of Guild, who had always interested himself so much in the welfare of their Institution. He coupled the toast with the name of Sir Alexander Richardson, a very able exponent of the technical press.

Sir ALEXANDER RICHARDSON, in reply, remarked that if he touched the fringe of criticism he hoped his constituents, the other guests, would believe that the only thing which actuated him was to do well for their profession and to do well for the nation at large. There was, he thought, a little too much tendency on the part of the members of the engineering and shipbuilding profession to introduce politics into the conduct of their affairs. Politics could do them little good. His friend Sir Alexander Kennedy would not differ from him when he said, "Have nothing whatever to do with Government support." Government support might help them for a day or an hour, but it invariably brought with it Government interference. There was nothing exact in political affairs. They were running an exact science, and everything must be founded on a true conception of the fundamental principles of that exact science. What was the most valuable raw material they had in this country or in any country in the world? The most valuable material was brains. Did they make certain that the brain-power they possessed was being utilised to the fullest?

Never in the history of this country had they had such a liberal flow of money for scholarships. What happened to the boys after they had gone through their scholarships? The Board of Trade, the Institution of Naval Architects, the Institution of Civil Engineers, their own organisation—did one of these institutions ever consider the future of the scholars? He had heard it said, "Oh, that is only a report of the scholarship

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work he did." Was that the right spirit to draw into any profession the brains which they had discovered, by alluding to a report as only a contribution of the scholar in regard to the work he did during the tenure of his scholarship? Brains would never be drawn into their profession unless an entirely different procedure from that was adopted. Some might say that the boys in past years had no more, or less, opportunity of bringing themselves to the front. To that he would reply that the ladder to climb to a good position in any profession was far, far harder to mount than it ever was before. Let them help these boys up the ladder, for until that was done the great industries of this country would not be founded on the truest basis conceivable. There were many profitable fields for the pursuit of physical phenomena. Let some of the apprentices after they had completed their college career be engaged in trying to explore avenues of physical phenomena. To-day they had Parsons, one of their best and greatest living engineers, moving out on his own financial responsibility into one of the greatest developments that had been made in marine engineering since he introduced the turbine. He was beset with difficulties; the physical phenomena which were up against this development were enormous. There was room in the laboratory of every single department of engineering activity to help him.

That had nothing to do with the other great department of marine engineering—the development of the internal-combustion engine. It was a tremendous pity to contemplate that they, the great leaders in steam machinery, were depending so largely on Continental engineers for their ideas about internal-combustion engines. How many firms in this country could say that they had begun to produce internal-combustion engines of their own design? It was a small matter, but it was a matter of the gravest significance for the future of engineering in this country. It was a case of the laboratory again, the cultivation of that brain power to which he had referred, and which, spread over those avenues of physical phenomena, would enor-

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mously benefit the people of this country. He did not blame them when they told him they had not enough money. He blamed them when they went and asked other people to help them solve their own problems. If in what he had said he had laid the seed of a new idea, then he would be a proud man.

Vice-Admiral Sir WALTER H. COWAN, Bt., who next acknowledged, said he felt very proud to have been invited to the dinner. The fame of the nation had been built on ships in the past, and here he was in a gathering of the most distinguished shipbuilders and engineers probably in Great Britain. There had been many comparisons drawn between the construction of British and German ships in the war to the disparagement of the former, because some of them sank in the Battle of Jutland after a very short time of fighting.

Their constructors were criticised to a certain extent for this, and possibly it did not do them any harm. They were rather full of what was called insular arrogance in that and in many other ways. But the point many people forgot was that the Germans built their ships for one purpose only, and that was to fight in the narrow waters of the North Sea, and, therefore, they did not require as much space for fuel as British ships, which were built to keep the whole world quiet, and consequently they sank a little easier than the German ships. Anybody who had seen through 40 years' service, as he had, ships crashing on the rocks and not breaking up, would realise the admiration Navy men had for those who built ships which stood the pounding that theirs did. In the days of sailing, ships were harnessed to the elements. They did not fight them. In present days they fought the elements. If there was one thing Britain could do it was to build ships.

The Navy, he was afraid, was regarded now as a somewhat necessary evil. They heard of economy and all that sort of thing. But it was no good living in a fool's paradise. While the world lasted then there must be war. They had finished with war for a time, but nobody could turn their backs to the

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fact that while human nature lasted, war must always be a possibility, and, therefore, they should not be carried away by people clamouring for unreasonable economy and voting for reductions in the Navy. Lord Rosebery once said that the largest naval programme ever put forward to Parliament was cheaper than the smallest war. Let them always remember that.

The CHAIRMAN thought they would all agree with what the gallant Admiral had said. To-day, as an insular people they must have a Navy. He thought they were all agreed upon that, and it was essential to do everything they could to uphold and support an efficient Navy. He would ask Mr. Berry to say a few words.

Mr. W. J. BERRY, C.B., Director of Naval Construction, said he did not agree that by comparison the British ship was inferior to the German ship, and that she would not stand the hammering and was sunk quicker. The first time the ships met it was a German ship that sank, on which occasion the Germans found that British shells got in under their decks and exploded the magazines. They immediately took steps to prevent their charges blowing up when the shells got in there. Britain, who did not lose a ship in that engagement, did not learn that lesson till the Jutland fight. After Jutland their magazines were put in order, and many other improvements with respect to shells, gun mountings, and equipment resulting from experience of that battle had been embodied in post-Jutland ships. In the last battleship built on the Clyde—the "Hood"—they had the benefit of practically all the lessons of Jutland. Of course, in the two new battleships now under construction the results of the lessons of Jutland were even more apparent. Alluding to destroyers, Mr. Berry said he supposed those present were the people responsible for 75 per cent. of all the destroyers built during the war. The Navy used to get delivery of about five or six destroyers every month. They went on their trials three days after steam was let into the engines, and were

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attached to the Fleet within a week. He thought that was a record at which every firm on the Clyde ought to be delighted. He had pleasure in congratulating Clyde engineers and shipbuilders on their achievements.

Lord LAMINGTON, who was also called upon, said that of course war was always a possibility, but he was a great believer that that possibility had been reduced by the work of the League of Nations. Still, they must have a Fleet. No doubt if the disarmament proposals came to anything, that Fleet might be still further reduced in size, but he trusted that the people of this country would always realise the necessity that their very lives depended upon having command of the seas, or, at all events, upon nobody else having command of the seas. He had heard of the supremacy of the Clyde being threatened by the Forth, but he believed the supremacy of the Clyde would last at all events their time.

Sir THOMAS PAXTON, ex-Lord Provost of the city, also responded.

The toast of "The Chairman" was afterwards proposed by Prof. P. A. HILLHOUSE, D.Sc., and Mr. CAMPBELL having acknowledged, the proceedings terminated.

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MINUTES OF PROCEEDINGS.

SIXTY-NINTH SESSION.

The First General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 6th October, 1925, at 7.30 p.m.

Mr. J. Howden Hume, the retiring President, occupied the chair.

The Minutes of the Annual General Meeting, held on 21st April, 1925, having been printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

Thereafter Mr. Hume introduced the new President, Mr. A. J. Campbell, who, he said, was one of the most eminent and distinguished members of the shipbuilding profession. He referred very briefly to Mr. Campbell's career at home and abroad, and expressed the hope that the Institution would have a very prosperous and successful session with Mr. Campbell as President.

Mr. Campbell then took the chair, and delivered his Presidential Address.

On the motion of Prof. P. A. Hillhouse, D.Sc., Vice-President, Mr. Campbell was accorded a hearty vote of thanks for his Address.

A paper entitled "The Ruths Steam Accumulator," by Mr. Alfred J. T. Taylor, of Toronto, was read, and the discussion thereon begun and adjourned.

The following candidates were elected:—

As Members.

Holden, Percy Edwin, Engineer, 4 Woodcroft Terrace, Jordanhill, Glasgow.

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JEFFERY, VIVIAN GREY TOOPE, Engineer, Hotel Furstenhof, Bochum, Germany.

MUNRO, WILLIAM SIM, Engineer, Bhanga, Cambridge Road, Renfrew.

WILKINSON, HERBERT, Engineer, 9 Sea View, Fort William.

From Associate Members.

BROWN, JOHN STEVEN, M.B.E., Engineer, Norwood, Esplanade, Greenock.

FULLERTON, JOHN, Shipbuilder, Abbotsburn, Paisley.

AS ASSOCIATE MEMBERS.

AHMAD, HAFIZ, B.Sc., Engineer, 30 Seymour Street, Crossmyloof, Glasgow, S.1.

HUNTER, STANLEY GODWIN, Engineer, Hawthornden, Ibroxholm, Ibrox, Glasgow.

RIPLEY, OSWALD HARBORD, Engineer, Messrs. Ruston & Hornsby, Ltd., Lincoln.

STIRRAT, FRANCIS BRACKENRIDGE, Engineer, 162 North Street, Charing Cross, Glasgow.

TAYLOR, JACK RAYMOND, Engineer, 260 George Street, Sydney, New South Wales, Australia.

From Students.

ANDERSON, ALFRED CRAWFORD, B.Sc., Engineer, c/o Unirea, Moreni, Jud Prahova, Roumania.

CRIGHTON, JOHN, Jun., Engineer, Hume Lodge, Tavistock Road, South Woodford, Essex, E.18.

AS AN ASSOCIATE.

ANDERSON, WILLIAM, Engineering Journalist, 9 Great George Street, Glasgow, W.2.

AS STUDENTS.

HILL, WILLIAM BROWN, B.Sc., Engineer, Argyll Lodge, Renfrew.

LANGLANDS, JOHN SCOTT, Apprentice Engineer, 1413 Pollokshaws Road, Glasgow, S.

MCLEAN, JOHN GRAHAM, Engineer, Dungoyne, Bishopbriggs, Glasgow.

STEPHEN, ALEXANDER MCLEOD MCADIE, Engineer, 17 Arlington Street, Glasgow, W.

The Second General Meeting was held in the Smoking Room of the Institution, 39 Elmbank Crescent, Glasgow, on Tuesday, 20th October, 1925, at 7.30 p.m.

Mr. A. J. Campbell, President, occupied the chair.

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The discussion on the paper entitled "The Ruths Steam Accumulator," by Mr. Alfred J. T. Taylor, was resumed and concluded.

On the motion of the Chairman, Mr. Taylor was accorded a vote of thanks for his paper.

A paper entitled "The Jubilee of the Marine Spring-Loaded Safety Valve," by Mr. Donald MacNicoll, was read, and the discussion thereon begun and adjourned.

The Third General Meeting was held in the Smoking Room of the Institution, 39 Elmbank Crescent, Glasgow, on Tuesday, 17th November, 1925, at 7.30 p.m.

Prof. Percy A. Hillhouse, D.Sc., Vice-President, occupied the chair.

The Minutes of the First and Second General Meetings, held on 6th and 20th October, 1925, respectively, having been printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

The discussion on the paper by Mr. Donald MacNicoll, entitled "The Jubilee of the Marine Spring-Loaded Safety Valve," was resumed and concluded.

On the motion of the Chairman, Mr. MacNicoll was accorded a vote of thanks for his paper.

A paper entitled "Possible Future Developments in Atlantic Express Passenger Services," by Mr. John Anderson, was read, and the discussion thereon begun and adjourned.

The following candidates were elected:—

HONORARY MEMBERS.

The Right Honourable EARL OF BALFOUR, K.G., O.M., P.C., F.R.S., D.L., LL.D.

Admiral of the Fleet the Right Honourable EARL BEATTY, O.M., G.C.B., G.C.V.O., D.S.O.

Sir DONALD MACALISTER of Tarbert, Bt., K.C.B., F.R.S.E., LL.D.

Rear-Admiral D. W. TAYLOR, U.S.N.

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As Members.

Bennie, Eric Matthew, Engineer, 36 Clarence Drive, Glasgow, W.2.

Black, Henry, Engineer, 3 St. James' Street, Hillhead, Glasgow, W.2.

Galbraith, Alexander, Engineer, Messrs. William Beardmore & Co., Ltd., Dalmuir.

Hall, James Drummond, Engineer, Samastipur, B. & N. W. Railway, District Darbhanga, Behar, India.

Lyle, William, Ship Surveyor, British Corporation Registry, c/o Messrs. Eisler, Reeves & Murphy, 3 Canton Road, Shanghai, China.

Mackay, John, Engineer, Messrs. William Beardmore & Co., Ltd., Dalmuir.

Perry, William Arthur, Engineer, Hazlemere, 35 Vernon Street, Saltcoats.

Stewart, Valentine Beardmore, C.B.E., Engineer, Parkhead Forge, Glasgow.

From Associate Member.

Martin, Archibald, Engineer, 41 Moidart Road, Halfwayhouses, Glasgow.

From Student.

Nithsdale, William, B.Sc., Engineer, Messrs. Yarrow & Co. (1922), Ltd., Scotstoun, Glasgow.

As Associate Members.

Hamid, Abdul, M.A., B.Sc., C.D.A., Engineer, c/o Postmaster, Amritsar, Punjab, India.

Baird, William, Engineer, Messrs. Edward Simpson & Co., Ltd., Rutherglen.

Drynan, William, Engineer, 8 Barfillan Drive, Cardonald.

Grant, Thomas, Engineer, Erskine Road, Cardonald.

McKendry, William, Engineer, 198 Gourlay Street, Springburn, Glasgow.

Manson, William, Engineer, Anchorage, Barfillan Drive, Cardonald.

Stone, Vincent Oliver, Engineer, 13 Hickman Street, Govanhill, Glasgow.

From Students.

Dalziel, Alexander, B.Sc., Engineer, Townhead, Thankerton, Lanarkshire.

Rutherfurd, Walter David, Engineer, The Dhamai Tea Co., Ltd., Dhamai Division, Juri P.O. & T.O., Sylhet, India.

As Students.

Cameron, Dugald Niven, Engineer, 40 Apsley Street, Partick W., Glasgow.

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DOAK, DUNCAN MARTIN, Engineer, 17 Millbrae Crescent, Langside, Glasgow.

FLEMING, JOSEPH GARDNER BOWMAN, Engineer, Thornhill, Irvine Road, Kilmarnock.

HAY, MATTHEW, Engineer, 10 Brig o' Lea Cottages, Neilston.

JOHNSON, RICHARD G., Engineer, 7 Westbank Quadrant, Hillhead, Glasgow, W.2.

KETCHEN, JOHN WILLIAM, Engineer, 3 Lethington Avenue, Glasgow, S.1.

LAIRD, PETER ALEXANDER, Engineer, Dorema, Kilmacolm.

McCRAE, NORMAN ALEXANDER, Draughtsman, 23 Doune Terrace, Kelvinside North, Glasgow.

McKERRAL, JOHN ARCHIBALD, Engineer, 25 Dorset Street, Glasgow, C.3.

McLAREN, JOHN WATT, Apprentice Engineer, 284 Maxwell Road, Pollokshields, Glasgow.

MATTHEWS, JOHN AYERST, Apprentice Shipbuilder, 2 Viewmount Drive, Maryhill, Glasgow.

MILLAR, WILLIAM ARROL, Engineer, Winton, Bishopbriggs, Glasgow.

MORRISON, JAMES L., Engineer, 9 Stuart Avenue, Scotstoun.

RITCHIE, WILLIAM, Engineer, 6 Kinfauns Terrace, Copland Road, Ibrox, Glasgow.

ROBERTSON, JAMES W., Engineer, 2 Victoria Drive, Scotstoun.

ROBSON, IAN CLARK, Apprentice Engineer, 22 Drumoyne Avenue, Govan, Glasgow.

SMAIL, CHARLES KAY HUTTON, Apprentice Engineer, 67 Partickhill Road, Glasgow, W.1.

The Fourth General Meeting was held in the Smoking Room of the Institution, 39 Elmbank Crescent, Glasgow, on Tuesday, 1st December, 1925, at 7.30 p.m.

Mr. A. J. Campbell, President, occupied the chair.

Mr. W. H. Riddlesworth, M.Sc., M.Eng., moved the adoption of the Report of the Council and Treasurer's Statement for session 1924-25. He commented upon the satisfactory nature of the balance sheet, which showed a surplus of £60 0s. 5d. after allowing £150 for depreciation of the building and furniture, and spending £351 on the internal decoration of the building. The Council, he said, had recently placed an order for the cleaning and preservation of the exterior of the fabric at a cost of about £570, and this expenditure would have to be met next year.

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Mr. J. L. Adam seconded the motion.

Mr. John S. Brown, M.B.E., asked what decision the Council had arrived at with respect to the award of medals for papers read before the Institution. The President replied that the Council had considered this matter, and had granted a premium of books to the value of £5 to Mr. Gilbert Austin for his paper on "A New Electric Drive for Ship and Other Auxiliaries," and also to Mr. T. R. Thomas, B.Sc., for his paper on "The Longitudinal Strength of Ships"; and that the Council had decided not to award a medal for any paper read last session.

Thereafter, the Report of the Council and Treasurer's Statement for session 1924-25 were unanimously adopted.

A paper entitled "The Commercial Application of Fuel Oil," by Mr. A. F. Baillie, was read, and the discussion thereon begun and adjourned.

The Fifth General Meeting was held in the Smoking Room of the Institution, 39 Elmbank Crescent, Glasgow, on Tuesday, 15th December, 1925, at 7.30 p.m.

Prof. Percy A. Hillhouse, D.Sc., Vice-President, occupied the chair.

The Minutes of the Third and Fourth General Meetings, held on 17th November and 1st December, 1925, respectively, having been printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

The discussion on the paper by Mr. John Anderson, entitled "Possible Future Developments in Atlantic Express Passenger Services," was resumed and concluded.

On the motion of the Chairman, Mr. Anderson was accorded a vote of thanks for his paper.

The discussion on the paper by Mr. A. F. Baillie, entitled "The Commercial Application of Fuel Oil," was resumed and concluded.

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On the motion of the Chairman, Mr. Baillie was accorded a vote of thanks for his paper.

A paper entitled "The Economic Value of Bunker Coal," by Mr. Otto Kahrs, was read by the Secretary, and the discussion thereon begun and adjourned.

The following candidates were elected:—

AS MEMBERS.

ALLAN, MALCOLM ALEXANDER, Engineer, Messrs. Clifton & Waddell, Engineers, Johnstone.

BUTLER, RICHARD JAGO, Engineer, Messrs. William Beardmore & Co., Ltd., Dalmuir.

CRONE, SCOTT, Engineer, 31 Arden Avenue, Thornliebank.

MACGREGOR, ALEXANDER, Engineer. 93 Dundrennan Road, Langside, Glasgow.

SCHOFIELD, PERCY, Engineer, 17 Valeview Terrace, Langside, Glasgow.

From Associate Member.

YOUSSEF, MOSTAFA R., B.Sc., A.R.T.C., Engineer, 48 Minard Road, Shawlands, Glasgow.

AS AN ASSOCIATE MEMBER.

SALEH, HUSSAIN MOHAMMAD, Engineer, c/o Caldwell, 60 Finlay Drive, Dennistoun, Glasgow.

AS STUDENTS.

DENNY, EDWARD LESLIE, Apprentice Engineer, Arolla, Cardross, Dumbartonshire.

LINDSAY, ROBERT, Engineer, 631 Hawthorn Street, Springburn, Glasgow.

MCLAY, JOHN MCCUTCHEON, Engineer, Heathbank, Springfield Road, Bishopbriggs.

MAUCHLINE, JAMES RAMAGE, Draughtsman, 18 Harvie Street, Glasgow, S.W.

OTTEWILL, REGINALD, Apprentice Engineer, 391 Kilmarnock Road, Newlands, Glasgow.

YOUNG, ALEXANDER JAMES, Apprentice Engineer, 130 Katherine Avenue, Linthouse, Glasgow.

YOUNG, PETER LESLIE, Apprentice Engineer, 46 Thornwood Avenue, Partick West, Glasgow.

The Sixth General Meeting was held in the Lesser Hall of the Institution, 39 Elmbank Crescent, Glasgow, on Tuesday, 12th January, 1926, at 7.30 p.m.

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Mr. A. J. Campbell, President, occupied the chair.

The discussion on the paper by Mr. Otto Kahrs, entitled "The Economic Value of Bunker Coal," was resumed and adjourned.

A paper entitled "Failure of Metals by Creep," by Prof. William Kerr, Ph.D., A.R.T.C., was read, and the discussion thereon begun and adjourned.

The Seventh General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 26th January, 1926, at 7.30 p.m.

Mr. A. J. Campbell, President, occupied the chair.

The Minutes of the Fifth and Sixth General Meetings, held on 15th December, 1925, and 12th January, 1926, respectively, having been printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

Thereafter the President presented a prize of books to Mr. Gilbert Austin for his paper entitled "A New Electric Drive for Ship and Other Auxiliaries," read before the Institution on 18th November, 1924, and to Mr. T. R. Thomas, B.Sc., for his paper entitled "The Longitudinal Strength of Ships," read on 13th January, 1925.

A paper entitled "The Werkspoor Diesel Engine," by Mr. G. J. Lugt, of Amsterdam, was read, and the discussion thereon begun and adjourned.

The following candidates were elected:—

AS MEMBERS.

BEWICK, JOHN WILLIAM, Engineer, The Asiatic Petroleum Co., Ltd., Shanghai, China.

MOUNTFORT, HAWORTH HILLARY, Engineer, Rata, 32 Shirley Road, Wollstonecroft, Sydney, New South Wales, Australia.

NICOLL, WILLIAM JOHN, Engineer, c/o The Asiatic Petroleum Co. (India), Ltd., Bombay, India.

TURNBULL, SAMUEL MCMURRAN, Shipbuilder, 75 Union Street, Greenock.

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As Associate Members.

LYON, IVAN MORAY, B.Sc., Engineer, c/o McKenzie, 494 Great Western Road, Glasgow.

SMITH, FRANCIS WILLIAM LOVATT, Engineer, Aldersyde, Grove Park, Lenzie.

From Student.

BALLANTINE, ARCHIBALD WILLIAM, B.Sc., Engineer, 8 Eglinton Drive, Kelvinside, Glasgow, W.2.

As an Associate.

ALLEN, ROBERT JOSEPH, Assistant Secretary, c/o Messrs. Harland & Wolff. Ltd., Govan Shipbuilding Works, Glasgow.

As Students.

GRAY, JAMES DRUMMOND, Ship Draughtsman, 1206 Govan Road, Glasgow.

MURRAY, JOHN RUDDOCK, Apprentice Engineer. Kenwood, Bishopbriggs, Glasgow.

SIMPSON, ARTHUR VERNON, Apprentice Engineer, c/o Purdie, 296 Maxwell Road, Pollokshields, Glasgow.

SMITH, ERNEST LOUDON, B.Sc., Apprentice Engineer, The Angle, Blairhill, Coatbridge.

WALKER, ARCHIBALD, Jun., B.A., Apprentice Engineer, 3 Albion Street, Dowanhill, Glasgow.

WALKER, JOHN MEIKLEJOHN, Jun., Ship Draughtsman, 27 Waverley Gardens, Crossmyloof, Glasgow.

The Eighth General Meeting was held in the Smoking Room of the Institution, 39 Elmbank Crescent, Glasgow, on Tuesday, 2nd February, 1926, at 7.30 p.m.

Mr. S. J. Pigott, Member of Council, occupied the chair.

The discussion on the paper by Mr. Otto Kahrs, entitled "The Economic Value of Bunker Coal," was resumed and concluded.

On the motion of the Chairman, Mr. Kahrs was accorded a vote of thanks for his paper.

The discussion on the paper by Prof. William Kerr, Ph.D.,

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A.R.T.C., entitled "Failure of Metals by Creep," was resumed and concluded.

On the motion of the Chairman, Prof. Kerr was accorded a vote of thanks for his paper.

The discussion on the paper by Mr. G. J. Lugt, entitled "The Werkspoor Diesel Engine," was resumed and adjourned.

The Ninth General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 9th February, 1926, at 7.30 p.m.

Mr. A. J. Campbell, President, occupied the chair.

A paper entitled "The Development of Increased Efficiency in Steam Application for Marine Purposes," by Sir James Kemnal, F.R.S.E., was read, and the discussion thereon begun and concluded.

On the motion of the Chairman, Sir James Kemnal was accorded a vote of thanks for his paper.

The discussion on the paper by Mr. G. J. Lugt, entitled "The Werkspoor Diesel Engine," was concluded.

On the motion of the Chairman, Mr. Lugt was accorded a vote of thanks for his paper.

The Tenth General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 23rd February, 1926, at 7.30 p.m.

Mr. A. J. Campbell, President, occupied the chair.

A paper entitled "Causes of Distortion in the Electrical Reproduction of Sound," by Capt. P. P. Eckersley, of the British Broadcasting Company, was read.

On the motion of the Chairman, Capt. Eckersley was accorded a vote of thanks for his paper.

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The following candidates were elected:—

As Members.

Brunton, David Duncan, Engineer, Jones Slipway & Engineering Co., Buckie.

Duncan, Robert Kirkwood, Shipbuilder, The Taikoo Dockyard & Engineering Co. of Hongkong, Ltd., Hongkong.

Reid, Alexander McKechnie, Engineer, Led-na-bra, Potterhill Avenue, Paisley.

As Associate Members.

Faheem, Mostafa, Engineer, 31 Cotham Vale, Redland, Bristol.

Mazen, Abdelwahab Abdulla, Engineer, 31 Cotham Vale, Redland, Bristol.

As Students.

Cameron, Donald, Apprentice Engineer, Dromore Cottage, Kirkintilloch.

Dalglish, John, Student of Engineering, 3 St. Bride's Road, Newlands, Glasgow.

The Eleventh General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 9th March, 1926, at 7.30 p.m.

Mr. A. J. Campbell, President, occupied the chair.

A paper entitled "The Development of the Nobel Engine," by Mr. P. H. Dixon Wilson, was read, and the discussion thereon begun and adjourned.

The Twelfth General Meeting was held in the Smoking Room of the Institution, 39 Elmbank Crescent, Glasgow, on Tuesday, 23rd March, 1926, at 7.30 p.m.

Prof. Percy A. Hillhouse, D.Sc., Vice-President, occupied the chair.

The Minutes of the Seventh, Eighth, Ninth, Tenth, and Eleventh General Meetings, held on 26th January, 2nd, 9th, and 23rd February, and 9th March, 1926, respectively, having been printed and circulated amongst the members, were held as read, and signed by the Chairman.

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The discussion on the paper by Mr. P. H. Dixon Wilson, entitled "The Development of the Nobel Engine," was concluded.

On the motion of the Chairman, Mr. Wilson was accorded a vote of thanks for his paper.

A paper entitled "The Bracketless System," by Sir Joseph W. Isherwood, Bt., and Mr. William Isherwood, was read, and the discussion thereon begun and adjourned.

The following candidates were elected:—

As Members.

McKenzie, John Jack, Chief Superintendent Engineer, Britannic House, Finsbury Circus, London, E.C.2.

Whyte, Claude George, Engineer, 52 Grant Street, Glasgow, C.3.

As an Associate Member.

Nomura, Seigo, Assistant Professor of Naval Architecture, College of Engineering, Kiushiu Imperial University, Fukuoka, Japan.

As Students.

Bury, Leslie F., Apprentice Engineer, 32 St. Andrew's Drive, Pollokshields, Glasgow.

Hunter, John, Engineer, 25 Wellgreen, Stirling.

Sharp, John, Apprentice Draughtsman, 66 Edmund Street, Dennistoun, Glasgow.

Williamson, James Harold, Apprentice Engineer, 10 Highland Road, Bromley, Kent.

The Thirteenth General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 13th April, 1926, at 7.30 p.m.

Mr. A. J. Campbell, President, occupied the chair.

The Secretary submitted the following nominations by the Council for Office-Bearers:—For Session 1926-27—*President*, Mr. A. J. Campbell. For Sessions 1926-29—*Vice-President*, Mr. W. W. Marriner. *Members of Council*, Messrs. Herbert Beard, Angus Campbell, Alexander James Hendin, O.B.E.,

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Adam Hunter, Harold D. Jackson, Ralph D. Moore, B.Sc., Alexander H. Weddell, B.Sc., and (from Associate Class) H. H. A. Greer.

The President remarked that the Council had carefully selected gentlemen who represented generally the interests which concerned the Institution, but if any member had any other nomination to make, the Council would be glad to receive it.

Thereafter, the nomination of Mr. James Richardson, B.Sc., was moved and seconded.

A paper entitled "Some Problems Relating to the Manufacture and Use of Rubber Tyres" was read by Mr. A. Healey, B.Sc., and the discussion thereon begun and adjourned.

The Annual General Meeting was held in the Smoking Room of the Institution, 39 Elmbank Crescent, Glasgow, on Tuesday, 4th May, 1926, at 7.30 p.m.

Mr. A. J. Campbell, President, occupied the chair.

The Minutes of the Twelfth and Thirteenth General Meetings, held on 23rd March and 13th April, 1926, respectively, having been printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

Dr. R. M. Brown and Mr. C. H. Wright were appointed Scrutineers to examine the ballot papers for the election of Office-Bearers for Sessions 1926-29.

The discussion on the paper by Sir Joseph W. Isherwood, Bt., and Mr. William Isherwood, entitled "The Bracketless System," was resumed and concluded.

On the motion of the Chairman, the authors were accorded a vote of thanks for their paper.

The discussion on the paper by Mr. A. Healey, B.Sc., entitled "Some Problems Relating to the Manufacture and Use of Rubber Tyres," was concluded.

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On the motion of the Chairman, Mr. Healey was accorded a vote of thanks for his paper.

A paper entitled "The Design of High-Speed Motor Boats," by Mr. W. G. A. Perring, was read, and the discussion thereon begun and concluded.

On the motion of the Chairman, Mr. Perring was accorded a vote of thanks for his paper.

Thereafter, Dr. Brown and Mr. Wright reported that, as a result of the ballot, the following members had been elected as Office-Bearers:—For Session 1926-27—*President*, Mr. A. J. Campbell. For Sessions 1926-29—*Vice-President*, Mr. W. W. Marriner. *Members of Council*, Messrs. Angus Campbell, Alexander James Hendin, O.B.E., Adam Hunter, Ralph D. Moore, B.Sc., James Richardson, B.Sc., and (from Associate Class) H. H. A. Greer.

The following candidates were elected:—

As Members.

Christie, John Reid, Engineer, 16 Erskine Road, Cardonald.

Crush, Samuel Thomas, Shipbuilder and Engineer, 90 Southbrae Drive, Glasgow, W.2.

Kanao, Tadayoshi, Professor of Mechanical Engineering, Fukui Technical College, Fukui, Japan.

Mervyn, Audley, Engineer, Asiatic Petroleum Co. (North China), Ltd., Shanghai, China.

Read, Charles Little, Engineer, 79 West Regent Street, Glasgow.

Scarth, Ninian H., Engineer, 71 Danes Drive, Scotstoun, Glasgow.

Seedhouse, Edward James Curry, Engineer, Auchenbank, 30 Kilmarnock Road, Giffnock, Glasgow.

As Associate Members.

Ahmed, Abdel Ghaffar, Engineer, His Majesty's Nile Yachts, Cairo, Egypt.

From Student.

Campbell, Thomas Cochrane, Ship Draughtsman, 71 Dixon Avenue, Crosshill, Glasgow.

As Students.

Cameron-Mackintosh, Angus Harry, Engineer, c/o Macdonald, 670 Eglinton Street, Glasgow, C.5.

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CONNARD, GEORGE BAER, B.Sc., Apprentice Engineer, 3 Hayburn Crescent, Partick, Glasgow, W.1.

DICKMAN, JAMES TENNANT, Engineering Draughtsman, c/o Miss Burns, Violetbank, Bishopbriggs, Glasgow.

LIDDELL, THOMAS WYLIE, Apprentice Engineer, 15 Regent Park Terrace, Strathbungo, Glasgow, S.1.

POULSON, HENRY WILLIAM, Apprentice Engineer, 140 West Graham Street, Glasgow, C.4.

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REPORT OF THE COUNCIL.

Session 1924-25.

Throughout a session during which the actual condition of the industries with which the Institution is related has steadily sunk to a very low level, it is a source of gratification to the Council to find that members realise the advantage of such institutions as ours as a means of keeping themselves abreast of all modern developments, and thus being in a position to seize their opportunity of building up a new prosperity. They have shown themselves particularly interested in regard to the number and quality of the papers read, and in the ensuing discussions.

The Council have pleasure in stating that the affairs of the Institution are in a very satisfactory condition, but urge all members to increase their personal and individual interest in the work it carries on.

The Roll.

The changes in membership during the year ending 30th September, 1925, are shown in the following statement:—

	Session 1923-24.	Session 1924-25.
Honorary Members - - -	2	6
Members - - - - -	1,037	1,049
Associate Members - - -	309	305
Associates - - - -	70	66
Students - - - - -	197	201
	1,675	1,627

The number of admissions to the register during the year was 78, while the transfers from a lower to a higher grade of

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membership were 20. Allowing for deletions on account of deaths, resignations, and non-payment of subscriptions, there is a decrease in membership of 48.

Members Deceased.

The Council deeply regret to report the following deaths:—

Members.—Walter Brown, Renfrew; Edward Bonar Caird. London; Archibald Cree, Dunoon; W. R. Cummins, Glasgow; John Duncan, Port-Glasgow; Robert Duncan, Glasgow; James Fullerton, Paisley; Thomas McGregor, Glasgow; R. B. Macouat, Glasgow; William W. May, Glasgow; William Millar, Jun., Greenock; D. B. Morison, Hartlepool; Frederick Teed Murdoch, London; John F. Rankin, Greenock; Sir James Scott, Tayport; James L. Scott, Glasgow; John A. Steven, Glasgow; John G. Stewart, Dunblane; Robert H. Warden, Valparaiso, Chile.

Associate Member.—Wallace Bruce McHardy, Dunblane.

Associates.—Thomas John Brown, Glasgow; Charles R. Stewart, Glasgow; Robert Young, Glasgow.

Students.—George M. Cunningham, Glasgow; Arthur W. C. Greer, Glasgow.

Meetings and Papers.

Fourteen meetings were held during the session, and at the opening meeting on 14th October the President delivered an address. He referred briefly to the prevailing industrial depression, which, he said, was due partly to the loss of our export trade, the change in the financial equilibrium of the world, the results arising out of the Washington Treaty, and the over-production of merchant ships during and immediately after the war. He suggested that, in order to secure a speedy solution of this vital problem which would be beneficial to the whole nation, the subject should be lifted entirely out of the political field and submitted to a court of investigation comprising equal numbers of manufacturers, workmen, merchants, and professional men.

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Following is a list of the papers presented and discussed:—

"Pulverised Fuel in Some Commercial Aspects," by A. J. T. Taylor.

"A Proposed Form of Bow Construction," by E. F. Spanner.

"A New Electric Drive for Ship and Other Auxiliaries," by Gilbert Austin.

"The Further Development of Large Power Diesel Engines," by W. D. McLaren.

"Internal-Combustion Locomotives," by James Dunlop.

"On the Longitudinal Strength of Ships," by T. R. Thomas, B.Sc.

"Straight-Frame Ships," by Dr. A. M. Robb.

"An Investigation into the Effects of Cold Drawing on Some Properties of Steel and Iron," by R. M. Brown, B.Sc., Ph.D.

"The Latest Type of the Burmeister & Wain Marine Diesel Engine," by H. H. Blache.

"Steam Pipes for Extra High Pressure and Temperature," by J. Arthur Aiton, C.B.E.

"The Manufacture of Brass Condenser Tubes, with Some Notes on an Alternative Alloy," by G. H. Whiteman and A. Spittle.

"The Internal-Combustion Turbine," by Prof. W. J. Goudie, D.Sc.

"Canadian Bulk Cargo Vessels on the Great Lakes," by William I. Hay and Duncan McArthur.

"The Aerodynamics of the Rotating Cylinder," by Alexander Thom, B.Sc.

The President's Address, together with the papers and discussions thereon, are published in Vol. LXVIII of the Institution's proceedings.

Appointment of Representatives.

The Council appointed Mr. W. W. Marriner to represent the Institution on The British Engineering Standards Association: Sub-Committee on Screw Threads, and Mr. George Brown on Lloyd's Technical Committee, *vice* Mr. James Fullerton, deceased.

Presentations to the Institution.

A sum of £2,000 from Sir Hugh Reid, Bart., C.B.E., LL.D., as a mark of his appreciation of the work carried on by the

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Institution in promoting the science and practice of engineering and shipbuilding, the annual revenue derived from the investment of this sum to be applied towards defraying the cost of publication of the Institution's proceedings.

A sum of £50 from the late Mr. James Fullerton, C.B.E., for Library purposes.

A framed mezzotint of the late Sir John Fowler, Bart., Civil Engineer; presented by Mr. J. E. Harrison.

A framed portrait of Baron Napier of Merchiston, inventor of logarithms, painted by the Scottish artist, J. Drummond; presented by Mr. A. W. Stewart.

A framed manuscript list of early Clyde-built steamers; presented by Mr. Walter Donald through Mr. James H. Anderson.

Two framed photographs of locomotive engines, built in 1825 and 1833 respectively; presented by Mr. C. P. Hogg.

Honours Conferred Upon Members.

The Council take this opportunity of offering their congratulations to the following members of the Institution upon whom honours have been bestowed:—

Baronetcy.

Lieut.-Col. James Lithgow, M.C., D.L.

Knight Commander of the Most Excellent Order of the British Empire.

Sir John Reid, J.P., D.L.

Doctor of Laws.

Mr. J. A. Roxburgh.

The "James Watt" Dinner.

The "James Watt" Dinner was held in the Banqueting Hall of the Grosvenor Restaurant, Glasgow, on Friday evening, 21st November, 1924. Mr. J. Howden Hume, President, occupied the chair, and the company numbered 360.

A special feature of the gathering was the musical pro-

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gramme, to which six members of the British National Opera Company contributed.

A report of the proceedings will be found in Vol. LXVIII.

Students' Section.

Seven monthly meetings were held during the session, at which papers on the following subjects were read and discussed:—

"General Patternmaking and Foundry Practice," by T. Kimpton and J. Crighton, Jun.

"Some Aspects of Engineering Economics," by J. McLeay, B.Sc.

"Gas Turbines," by Prof. W. J. Goudie, D.Sc.

"Ship Design," by Prof. Percy A. Hillhouse, D.Sc.

"Modern Production Methods," by J. M. Shea, B.Sc.

"Marine Oil Fuel Burning Installations," by F. R. Topping, B.Sc.

Visits to works were arranged by the Council, and the Students desire to express their thanks to the authorities of the following establishments for the facilities afforded and the kindness shown during these visits:—

The Central Fire Station, Glasgow.
Messrs. Wm. Dixon, Ltd., Govan Iron Works.
Messrs. John Brown & Co., Ltd., Clydebank.
Provan Gas Works, Glasgow.
Messrs. John Tullis & Son, Ltd., Bridgeton.
Albion Motor Car Co., Ltd., Scotstoun.
Messrs. John Watson, Ltd., Robroyston Colliery.
British Oxygen Co., Ltd., Polmadie.
North British Diesel Engine Works (1922), Ltd., Whitcinch.

A Concert and informal Dance was held in the Smoking Room of the Institution on Friday evening, 30th January, 1925.

A Smoking Concert was held in the Smoking Room on Friday evening, 27th March, 1925, when an excellent programme of vocal and instrumental music was submitted.

Mr. R. D. Moore, B.Sc., presided on both occasions.

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Mr. J. L. Adam was appointed to succeed Mr. R. D. Moore, B.Sc., as President.

Tenant Societies.

The following societies hold their sessional meetings in the Institution's premises:—

British Empire Shakespeare Society.
British Music Society.
Glasgow and West of Scotland Association of Foremen Engineers and Draughtsmen.
Glasgow Institute of Architects.
Glasgow Master Wrights' Association.
Glasgow Practical Psychology Club.
Institute of Metals—Local Section.
Institution of Civil Engineers—Glasgow Association of Students.
Scottish Society of Industrial Welfare Supervisors.
Society of Chemical Industry—Glasgow Section.
Society of Consulting Marine Engineers and Ship Surveyors—Scottish District.

Finance.

The surplus revenue for the year ending 30th September, 1925, as shown in the Treasurer's Statement, appended hereto, is £60 0s. 5d.

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TREASURER'S
INCOME AND EXPENDITURE ACCOUNT
GENERAL

ORDINARY INCOME.		1924-1925.	1923-1924.
I. *Annual Subscriptions received—*			
Members	£2,807 15 0		
Associate Members ...	579 15 11		
Associates	135 0 0		
Students	139 10 0		
		£3,662 0 11	*£3,797 0 0*
II. *Arrears of Subscriptions recovered* ...		68 5 0	*89 10 0*
III. *Sales of "Transactions"*		251 18 4	*152 4 6*
IV. *Interests and Rents—*			
Interest on Deposit Receipts	£45 15 4		
Interest on Clyde Trust Mortgages	231 10 0		
Interest on 5% War Stock	112 10 0		
Sundry Rents	413 11 0		
		803 6 4	*825 14 10*
V. *Advertisement Receipts, less cost of Printing*		272 3 0	*381 9 6*
EXTRAORDINARY INCOME.			
Sir Hugh Reid, Bt. Donation to Printing of Transactions		2,000 0 0	
James Fullerton. Donation to Library		50 0 0	
		£7,107 13 7	*£5,245 18 10*

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STATEMENT.
FOR THE YEAR ENDING 30TH SEPTEMBER, 1925.
FUND.

ORDINARY EXPENDITURE.			1924-1925.	*1923-1924.*
I. *Management Expenses*—				
Salaries £1,365 5 8				
Stationery, Postages, etc. ... 97 8 1				
General Printing 192 16 0				
Office Expenses ... 63 15 1				
Coffee Room Account ... 16 1 8				
Lithography ... 9 8 3				
Travelling Expenses 17 0 5				
Library Books 15 18 9				
		£1,777 13 11		
II. *House Expenses*—				
Feu-Duty, Taxes, and Insurance £564 4 5				
Caretaker and Cleaning ... 341 11 11				
Maintenance and Repairs ... 26 0 10				
Heating and Lighting ... 188 2 2				
Depreciation—				
Buildings ... 100 0 0				
Furniture and Fittings ... 50 0 0				
		1,269 19 4		
			£3,047 13 3	*£2,946 9 5*
III. "*Transactions*" *Expenses*—				
Printing and Binding ...	£1,384	10 5		
Postages	106	8 11		
Reporting	49	5 7		
Delivery of Volume (Est.) ...	58	0 0		
			1,598 4 11	*2,080 2 6*
EXTRAORDINARY EXPENDITURE ...				
Cleaning and Painting Interior of Buildings, etc.	£351	15 0		
Transferred to Bequest Funds—*see* Balance Sheet	2,050	0 0		
			2,401 15 0	*132 17 10*
Surplus carried to Balance Sheet			60 0 5	*86 9 1*
			£7,107 13 7	*£5,245 18 10*

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BALANCE SHEET, AS AT

LIABILITIES.				As at 30th Sept., 1925.			*As at 30th Sept., 1924.*		
I. *General Capital Account*—									
As at 1st October, 1924			£32,364	0	0				
Entry Money...			39	0	0				
Surplus from Revenue ...			60	0	5				
						£32,463	0	5	*£32,364*	*0*	*0*
II. *Life Members' Subscriptions*			...		...	1,677	2	0	*1,677*	*2*	*0*
III. *Feu-Duty and Taxes accrued*			...		...	190	0	0	*185*	*0*	*0*
IV. *Sundry Creditors*			...		...	1,837	12	5	*1,877*	*9*	*6*
V. *Subscriptions paid in advance*			...		...	78	5	0	*70*	*10*	*0*
VI. *Social Fund*			...		...	130	5	5	*99*	*3*	*6*
VII. *Medal Funds*—									
Marine Engineering—									
Balance as at 1st Oct., 1924	£1,076	16	3						
Interest received	46	16	6						
			£1,123	12	9				
Railway Engineering—									
Balance as at 1st Oct., 1924	£719	8	11						
Interest received	31	5	4						
			750	14	3				
Students'—									
Balance as at 1st Oct., 1924	£572	16	1						
Interest received	25	7	2						
Grant from "Buchanan and Ewing Bequests"	50	0	0						
	£648	3	3						
Less cost of Technical Books	55	0	0						
			593	3	3				
						2,467	10	3	*2,369*	*1*	*3*
VIII. *Bequest Funds*—									
Sir Hugh Reid, Bt. ...			2,000	0	0				
James Fullerton ...			50	0	0				
						2,050	0	0			
						£40,893	15	6	*£38,642*	*6*	*3*

ON BEHALF OF THE COUNCIL,

A. J. CAMPBELL, *President.*
ROBT. THOS. MOORE, *Honorary Treasurer.*

GLASGOW, 16*th November*, 1925.—I have audited the Books and Accounts of 30th September, 1925, and have to report that I have obtained all the information Sheet is properly drawn up so as to exhibit a true and correct view of the state of my information and the explanations given to me, and as shown by the Books.

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30TH SEPTEMBER, 1925.

ASSETS.			As at 30th Sept., 1925.	As at 30th Sept., 1924.
I. *Buildings Account* ...	£26,000 0 0			
Less Depreciation	100 0 0			
		£25,900 0 0	£26,000 0 0	
II. *Furniture and Fittings* ...	500 0 0			
Less Depreciation	50 0 0			
		450 0 0	500 0 0	
III. *Books in Library*—				
Valued at, say		500 0 0	500 0 0	
IV. *Investment Account*—				
Clyde Trust Mortgages ..	£4,500 0 0			
5% War Stock (1929-1947) ...	2,191 6 6			
		6,691 6 6	6,691 6 6	
V. *Medal Funds Investments*—				
Clyde Trust Mortgages ...	£1,300 0 0			
On Deposit Receipt	1,155 5 8			
NOTE.—Balance of £12 4 7 since lodged on Deposit Receipt.		2,455 5 8	£2,364 1 5	
VI. *Bequest Funds Investment*—				
Clyde Trust Mortgage		2,050 0 0		
VII. *Arrears of Subscriptions*—				
Session 1924-25—				
Members	£170 0 0			
Associate Members	45 5 0			
Associates	6 15 0			
Students	14 5 0			
	£236 5 0			
Previous Sessions—				
Members £93 0 0				
Associate Members 6 10 0				
Associates ... 4 10 0				
	104 0 0			
Total	£340 5 0			
Valued at, say...	... ...	50 0 0	50 0 0	
VIII. *Rents, Interests, etc., accrued*	... ...	269 19 9	242 1 8	
IX. *Cash*—				
In Bank on D/R ...	£2,315 2 5			
On Current Account ...	... 256 19 9			
	£2,572 2 2			
Less due Secretary ...	.. 44 18 7			
		2,527 3 7	2,294 16 5	
		£40,893 15 6	£38,642 6 3	

the Institution of Engineers and Shipbuilders in Scotland for the year ending and explanations I have required, and that, in my opinion, the foregoing Balance of the Institution's affairs as at 30th September, 1925, according to the best

DAVID BLACK, C.A., *Auditor.*

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REPORT OF THE LIBRARY COMMITTEE.

During the Session the accessions to the Library were 297 volumes and pamphlets. Of these 15 were Board of Trade Reports on Boiler and Steam-pipe Explosions; 31 British Engineering Standards Association publications; 55 volumes of Abridgments of Specifications of Patents; 22 volumes and pamphlets by donation; 114 volumes and pamphlets by exchange, and 60 volumes by purchase.

In addition to the books consulted in the Library and Reading-Room, 944 were loaned to 612 borrowers. This number included 640 complete works, 137 volumes of transactions, proceedings of technical institutions, etc., 117 periodicals, etc., and 50 Abridgments of Specifications of Patents.

The Institution exchanges transactions with 78 scientific societies; there are also received in exchange 76 periodicals, 29 being weekly, 45 monthly, and 2 quarterly.

The Institution possesses a set of Abridgments of Specifications of Patents from the year 1617, and files of the principal periodicals are kept.

The Library Committee will be pleased to receive gifts of technical books, etc., to be preserved in the Library for reference.

LIBRARY ACCESSIONS.

By Donation.

Abridgments of Specifications of Patents. 55 volumes. Series 1916-1920. From the Patent Office.

American Society of Mechanical Engineers. Boiler Furnaces for Pulverized Coal. New York. 1925. pph. From the Society.

Bacon, Prof. F. Steam Power with Special Reference to the Uniflow Engine. Cardiff. 1925. From the Author.

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British Engineering Standards Association Publications :—

British Standard Dimensions for Parallel Keys, Keyways, and Key Bars. No. 46. (Part I.) 1924. (Partly superseding No. 46. 1909.)

British Standard Sections of Steel Fishplates for Flat Bottom Railway Rails. No. 47a. 1924. (Partly superseding No. 47a. 1919.)

British Standard Specification for Metallic Resistance Materials for Electrical Purposes. No. 115. 1924. (Superseding No. 115. 1921.)

British Standard Specification for Hard-Drawn Copper Solid and Stranded Circular Conductors for Overhead Power Transmission Purposes. No. 125. 1924.

British Standard Specification for Normal Type Tungsten Filament Electric Lamps. No. 161. 1924. (Superseding No. 133. 1921.)

British Standard Limits and Fits for Engineering. No. 164. 1924. (Superseding No. 27. 1906.)

British Standard Dimensions of Spanners. No. 192. 1924. (Partly superseding No. 28. 1908.)

British Standard Specification for Electrolytic Copper Ingots and Ingot Bars. No. 199. 1924.

British Standard Specification for Tough Copper Cakes and Billets for Rolling. No. 200. 1924.

British Standard Specification for Fine Copper Cakes for Rolling. No. 201. 1924.

British Standard Specification for Electrolytic Cathode Copper. No. 202. 1924.

British Standard Specification for "Best Select" Copper. No. 203. 1924.

List of Terms and Definitions used in connection with Telegraphs and Telephones. No. 204. 1924.

British Standard Specification for Fuels for Heavy-Oil Engines (Petroleum and Shale Oils). No. 209. 1924.

British Standard Classification of Pure Mineral Lubricating Oils. No. 210. 1924.

British Standard Specification for Marine Flanges (for working pressures of 55, 125, 225, and 325 lbs. per sq. in.). No. 3022. 1924.

British Standard Interim Specification for Cast Iron Piston Ring Pots (Sand Cast and Chill Cast) for Automobiles. No. 5004. 1924.

British Standard Schedule of Wrought Steels for Automobiles. No. 5005. 1924. (Superseding No. 75. 1916.)

British Standard Schedule of Sheet Steels for Automobiles. No. 5007. 1924.

British Standard Schedule of Steel Tubes for Automobiles. No. 5009. 1924.

British Standard Dimensions for Pneumatic Tyre Rims. No. 5013. 1924. (Superseding Nos. 70. 1915, and C.L. 8564. 1920.)

Table of British Standard Unit Loadings for Railway Girder Bridges and Highway Girder Bridges. No. 153. (Parts 3, 4, and 5. 1923.) Appendix I. 1925.

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British Standard Specification for Bus-Bars and Connections constructed of Bare Copper or Aluminium. No. 159. 1925.

British Standard Specification for Brass Bars and Sections suitable for Forgings and Drop Forgings. No. 218. 1925.

British Standard Specification for Soft Solders (Grades A, B, C, D, E, F, G, H, and J). No. 219. 1925.

British Standard Dimensions of Wide Type Concentric Piston Rings. No. 5003. 1925. (Superseding No. 5003. 1922.)

British Standard Schedule of Steels for Laminated Springs for Automobiles. No. 5010. 1925.

British Standard Dimensions for Carburettor Flanges (2-Bolt Type). No. 5029. 1925.

British Standard Method for the Calibration of Carburettor Jets for Aircraft and Automobile Engines. No. 5030. 1925.

Address by Mr. C. le Maistre, C.B.E., given in Prague and Brno, at the Invitation of The Czecho-Slovakian Engineering Standards Committee. No. C.A. (F.T.) 8195. 1925.

Indexed List of British Standard Specifications and Reports, January, 1925.

Brown, J. R. Nautical Almanac for 1926. From the Publishers.

Duncan, W. J. The Carburettor considered from the Hydraulic Point of View. London. 1925. pph. From the Author.

Empire Mining and Metallurgical Congress. Part I—General; Part II—Mining; Part III—Petroleum; Part IV—Metallurgy of Iron and Steel; Part V—Non-Ferrous Metallurgy. London. 1925. From Mr. Sam Mavor.

Glasgow Corporation Public Libraries. Bulletin of Additions. No. 3. Glasgow. 1925. From the Corporation.

Hatfield, Dr. W. H. Modern Developments in the Metallurgy of Special Steels. London. 1925. pph. The Stainless Chromium Steels. pph. From the Author.

Information Bureaux and Special Libraries. Report of Proceedings of the First Conference. London. 1925. From the Committee.

Institute of Metals. Seventh Report of the Corrosion Research Committee. From Mr. J. G. Weir, C.M.G., C.B.E.

Kempe, H. R., ed. The Engineer's Year-Book for 1925. London. 1925. From the Editor.

Snow, Captain E. Recent and Early Information about Ancient and Medieval Ships. New York. 1925. From the Author.

The Chartered Institute of Secretaries. Year-Book for 1924-25. London. From the Institute.

The Motor Boat. Vols. XL and XLI. London. 1924. From the Proprietors.

The Motor Ship. Vol. V. London. 1924-25. From the Proprietors.

The Shipbuilder. Vol. XXXI. Newcastle. 1924. From the Proprietors.

The Society of Incorporated Accountants and Auditors. Year-Book. London. 1925. From the Society.

The Committee desire to thank cordially the donors of books and pamphlets to the Library.

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By Purchase.

Adam, A. T. Wire-Drawing and the Cold Working of Steel. London. 1925.

Air Ministry. Handbook of Strength Calculations. 2nd ed. London. 1924.

Angle, G. D. Engine Dynamics and Crankshaft Design. Detroit. 1925.

Berard, S. J., and Waters, E. O. The Elements of Machine Design. London. 1924.

Bond, W. N. An Introduction to Fluid Motion. London. 1925.

Byerly, W. E. An Introduction to the Use of Generalized Coördinates in Mechanics and Physics. Boston. 1916.

Carpenter, L. Mechanical Mixing Machinery. London. 1925.

Cocking, W. C. The Calculations for Steel-Frame Structures. 2nd ed. London. 1925.

Concrete Publications Ltd. Concrete Roads and their Construction. 2nd ed. London. 1923.

Coston, E. P. A Graduated Course in Strength and Elasticity of Materials. Vols. I and II. London. 1925.

Cunningham, B. Port Administration and Operation. London. 1925.

Curtis, J. W. Organisation of Production. London. 1924.

Dunell, H. British Wire-Drawing and Wire-Working Machinery. London. 1925.

Elliott, C. Distillation Principles. London. 1925.

Faber, O. Reinforced Concrete Beams in Bending and Shear. London. 1925.

Faber, O. Simple Examples of Reinforced Concrete Design. London. 1924.

Fischer, F. The Conversion of Coal into Oils. London. 1925.

Fry, L. H. A Study of the Locomotive Boiler. London. 1924.

Fuller, C. E., and Johnston, W. A. Applied Mechanics. Vol. I—Statics and Kinetics. New York. 1913.

Gibson, A. H. Hydraulics and its Applications. 3rd ed. London. 1925.

Gilbert, A. T. Gas Meters. London. 1925.

Goodrich, W. F. Pulverised Fuel. London. 1924.

Hanton, W. A. Mechanics of Textile Machinery. London. 1924.

Hardy, A. C. Motorships. London. 1925.

Hiscox, W. J. Factory Lay-out, Planning, and Progress. London. 1924.

Jeffries, Z., and Archer, R. S. The Science of Metals. New York. 1924.

Judge, A. W. Motor Manuals. Vol. I—Automobile Engines; Vol. II—Carburettors and Carburation; Vol. III—The Mechanism of the Car. London. 1925.

Kelly, E. T. Welfare Work in Industry. London. 1925.

Korevaar, A. Combustion in the Gas Producer and the Blast Furnace. London. 1924.

Lomax, J. The Microstructure of a Coal Seam. London. 1925.

Marquand, H. S. Electric Welding. London. 1920.

Maurer, E. R., and Roark, R. J. Technical Mechanics. New York. 1925.

Mechanical Properties of Fluids. A Collective Work. 2 Copies. London. 1925.

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Munro, R. D., and Ness, G. Steam Boilers. 6th ed. London. 1925.
Pilkington, T. Time Standardisation of Workshop Operations. London. 1925.
Plummer, T. H. Compressed Air and its Machinery. London. 1925.
Pollitt, A. A. The Technology of Water. London. 1924.
Regnauld, A. Modern Power Engineering. Vols. I, II, III, and IV. London. 1924.
Salmon, E. H. Columns. London. 1921.
Sanden, H. V. Practical Mathematical Analysis. London. 1923.
Schotz, S. P. Synthetic Organic Compounds. London. 1925.
Scott, W. L. Reinforced Concrete Bridges. London. 1925.
Seaton, A. E. Marine Engineering. 19th ed. London. 1921.
Sim, J. Steam Condensing Plant. London. 1925.
Smith, R. M. The Design and Construction of Small Craft. London. 1924.
Taylor, W. T. Practical Water-Power Engineering. London. 1925.
Verity, E. R. Mathematics for Technical Students. London. 1924.
Waring-Brown, R. Friction Clutches. London. 1924.
Wedmore, E. B., and Onslow, D. V. Electrical Engineers' Data Books. Vol. I—Lighting, Traction, and Power Distribution; Vol. II—Manufacture, Design, and Laboratory Work. London. 1925.
Wedmore, E. B., and Reyner, J. H. Electrical Engineers' Data Books. Vol. III—Radio Engineering. London. 1925.
White, H. J. Oil Tank Steamers. 3rd ed. Glasgow. 1925.
Whyatt, H. G. Highway Engineer's Year Book for 1925. London. 1925.

THE INSTITUTION EXCHANGES TRANSACTIONS WITH THE FOLLOWING SOCIETIES, ETC.:—

Aberdeen Association of Civil Engineers, Aberdeen.
American Institute of Electrical Engineers, New York.
American Institute of Mining and Metallurgical Engineers, New York.
American Philosophical Society, Philadelphia.
American Society of Civil Engineers, New York.
American Society of Mechanical Engineers, New York.
American Society of Naval Engineers, Washington.
Association des Ingénieurs sortis des Ecoles Spéciales de Gand, Gand.
Association Technique Maritime et Aéronautique, Paris.
Barrow and District Association of Engineers, Barrow.
British Association for the Advancement of Science, London.
British Corporation for the Survey and Registry of Shipping, Glasgow.
Bureau of Steam Engineering, Navy Department, Washington.
Bureau Veritas International Register of Shipping, Paris.
Chemical, Metallurgical, and Mining Society of South Africa, Johannesburg.
École Polytechnique, Paris.
Engineering Institute of Canada, Montreal.
Engineering Society of the School of Practical Science, Toronto.

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Franklin Institute, Philadelphia.
Huddersfield Engineering Society, Huddersfield.
Institute of Marine Engineers, London.
Institute of Metals, London.
Institution of Automobile Engineers, London.
Institution of Civil Engineers, London.
Institution of Civil Engineers of Ireland, Dublin.
Institution of Electrical Engineers, London.
Institution of Engineers, Australia, Newcastle Branch, New South Wales.
Institution of Engineers, Australia, Sydney.
Institution of Gas Engineers, London.
Institution of Mechanical Engineers, London.
Institution of Mining Engineers, London.
Institution of Municipal and County Engineers, London
Institution of Naval Architects, London.
Institution of Railway Signal Engineers, Derby.
Iron and Steel Institute, London.
Junior Institution of Engineers, London.
Literary and Philosophical Society of Manchester, Manchester.
Liverpool Engineering Society, Liverpool.
Lloyd's Register of British and Foreign Shipping, London.
Manchester Association of Engineers, Manchester.
Massachusetts Institute of Technology, Cambridge, Mass.
Midland Institute of Mining, Civil, and Mechanical Engineers, Sheffield.
Mines Branch, Department of Mines, Ottawa.
Mining Institute of Scotland, Glasgow.
Municipal School of Technology, Manchester.
National Physical Laboratory, Teddington.
Norske Veritas Register of Shipping, Oslo.
North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne.
North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
Nova Scotian Institute of Science, Halifax, N.S.
Patent Office, London.
Professional Memoirs, Corps of Engineers, United States Army, Washington.
Royal Aëronautical Society, London.
Royal Canadian Institute, Toronto.
Royal Dublin Society, Dublin.
Royal Philosophical Society, Glasgow.
Royal Scottish Society of Arts, Edinburgh.
Royal Society of Arts, London.
Royal Society of Edinburgh, Edinburgh.
Rugby Engineering Society, Rugby.
Scientific Library, U.S. Patent Office, Washington.

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Scientific Society of the Royal Technical College, Glasgow.
Smithsonian Institution, Washington.
Société d'Encouragement pour l'Industrie Nationale, Paris.
Société des Ingénieurs Civils de France, Paris.
Société des Sciences Physiques et Naturelles de Bordeaux, Bordeaux.
Société Industrielle de Mulhouse, Mulhouse.
Society of Engineers, London.
Society of Naval Architects and Marine Engineers, New York.
South Wales Institute of Engineers, Cardiff.
University of Cambridge, Cambridge.
University of Illinois Engineering Experiment Station, Urbana.
University of Liverpool, Liverpool.
University of Sheffield, Sheffield.
University of Toronto, Toronto.
Victorian Institute of Engineers, Melbourne.
West of Scotland Iron and Steel Institute, Glasgow.
Western Society of Engineers, Chicago.

Publications Received Periodically in Exchange for Institution's Transactions:—

Weekly.

American Machinist.
Autocar.
Automotor Journal.
Canadian Machinery.
Colliery Guardian.
Electric Railway and Tramway Journal.
Electrical Review.
Engineer.
Engineering.
Fairplay.
Flight.
Indian Engineering.
Iron and Coal Trades Review.
Journal de la Marine Marchande.
Journal of Commerce (Thursday issue).
L'Industria: Rivista Tecnico-Scientifica ed Economica.
Machinery.
Machinery Market.
Manchester Guardian Commercial.
Mechanical World.
Modern Transport.
Motor Boat.
Motor World.
Nautical Gazette.
Shipbuilding and Shipping Record.
Shipping World.
Syren and Shipping.
Times Engineering Supplement.
Wireless World.

Monthly.

American Marine Engineering and Shipping Age.
American Motorship.
Association of Drop Forgers and Stampers.
Automobile Engineer.
British and Latin American Trade Gazette.
British Engineers' Export Journal.
Bureau Veritas—Bulletin Technique.

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City and Guilds (Engineering) College Journal—The Central.
Civil Engineering.
Cleveland Scientific and Technical Institution Bulletin.
Cold Storage and Produce Review.
Colliery Engineer.
Colville's Magazine.
Combustion.
Compressed Air Magazine.
Concrete and Constructional Engineering.
Engineering and Boiler House Review.
Engineering Production.
Gas and Oil Power.
Indian and Eastern Engineer.
Indian and Eastern Motors.
Industrial India.
Industrial Management.
Irish Electrician.
Iron and Steel of Canada.
Journal of Chamber of Commerce, Aberdeen.
Journal of Chamber of Commerce, Belfast.
Journal of Chamber of Commerce, Edinburgh.
Journal of Chamber of Commerce, Glasgow.
Journal of the Royal Technical College, Glasgow.
Marine Engineer.
Marine Engineer Officers' Magazine.
Merchant Shipping Review and Empire Trade Gazette.
Metropolitan Vickers Gazette.
Motor Ship.
Nautical Magazine.
Oil Engineering and Finance.
Popular Science Monthly.
Powership.
Science Abstracts.
Shipbuilder.
South African Engineering.
Sperryscope.
Structural Engineer.
Tramway and Railway World.

Quarterly.

Shepherd's N.E.W.S.
The M. & C. (Mavor & Coulson) Apprentices' Magazine.

The Library and Reading-Room are open for the use of Members, Associate Members, Associates, and Students.

The Portrait Album lies in the Library for the reception of Members' Portraits. Members are requested when forwarding Portraits to attach their Signatures to the bottom of Carte.

The Library Committee are desirous of calling the attention of Readers to the "Recommendation Book," where entries can be made of titles of books suggested as suitable for addition to the Library.

As arranged by the Council, a Register Book for Students lies in the Library for the inspection of Members, the object being to assist Students of the Institution in finding suitable appointments.

GEORGE BROWN,
Hon. Librarian and Convener.

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REPORTS OF INSTITUTION'S REPRESENTATIVES ON VARIOUS BOARDS.

The Institution was represented on the following boards and committees:—

Advisory Committee for the William Froude National Tank, by Mr. P. D. Ewing, C.B.E.;

Board of Governors of the Glasgow and West of Scotland Commercial College, by Prof. A. L. Mellanby, D.Sc.;

Board of Governors of the Glasgow School of Art, by Mr. Laurence MacBrayne, O.B.E., M.A.;

Board of Governors of The Royal Technical College, Glasgow, by Mr. Harold E. Yarrow, C.B.E.;

Board of Trade Consultative Committee, by Mr. A. J. Campbell, Mr. J. Howden Hume, and Mr. C. Randolph Smith;

British Corporation Technical Committee, by Prof. P. A. Hillhouse, D.Sc., and Eng.-Capt. W. Onyon, M.V.O., R.N.;

British Engineering Standards Association: Sectional Committee on Cast Iron, by Mr. R. D. Moore, B.Sc.;

British Engineering Standards Association: Sectional Committee on Gears, by Mr. N. O. Fulton;

British Engineering Standards Association: Sectional Committee on Machine Parts, their Gauging and Nomenclature, by Dr. T. Blackwood Murray;

British Engineering Standards Association: Sectional Committee on Petroleum Products, by Dr. T. Blackwood Murray;

British Engineering Standards Association: Sub-Committee on Screw Threads, by Mr. W. W. Marriner;

British Engineering Standards Association: Sub-Committee on Steel Flanges for Hydraulic Pressure, by Mr. T. A. Hayward;

British Marine Engineering Design and Construction Committee, by Mr. James Brown, C.B.E., Mr. James S. Kincaid, O.B.E., and Mr. William G. Weir, O.B.E.;

Institute of Metals: Corrosion Research Committee, by Mr. James G. Weir, C.M.G., C.B.E.;

Institution of Civil Engineers: Committee on Tabulating the Results of Heat-Engine and Boiler Trials, by Prof. A. L. Mellanby, D.Sc., Mr. R. B. Mitchell, Mr. James Richardson, B.Sc., and Eng.-Com. W. McK. Wisnom, R.N.;

Joint-Committee on the Organisation of Classes in Science and Technology, by Mr. N. O. Fulton;

Lloyd's Technical Committee, by Mr. James Brown, C.B.E., Mr. George Brown, Mr. William Millar, O.B.E., and Mr. F. E. Rebbeck.

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The following are reports from these representatives:—

William Froude National Tank.

The demand for tests of both ships and propellers steadily increased during the year, and it is noteworthy that the greater number of designs submitted to test were for oil-engined ships of the cargo-carrying class. It was necessary to go a little more closely into propeller design with this type of engine than with the ordinary steam reciprocating-engine, and builders were naturally anxious to obtain good working conditions, especially for any new variety of engine.

The number of models tested for shape of hull was 52, and 10 forms were tried for appendage resistance. The 52 models represent 27 different designs, three of which were partially dealt with last year. An analysis of the 24 designs of the year shows that a little over 48 per cent. were for oil-engine propulsion, 31 per cent. for steam reciprocating-engines, and 11 per cent for turbine engines. One was a paddle steamer, and the mode of propulsion in two cases was unknown. Of the 27 designs, three were tested to determine the most suitable of different designs drawn out by the firms concerned. Six others when tested were found to be quite good in performance, and were not altered. Two models were drawn out at the tank without guidance lines from the firms, and as the results were good no further tests were made. Sixteen were altered in shape at the tank, and 14 were improved by the changes made. The average reduction in power required for propulsion in these 16 designs was approximately six per cent., the greatest gain in any individual case being 16 per cent., of which one-half was on hull form and the rest on the screw propeller.

The types of vessel dealt with during the year include destroyers, liners, ocean and coastal cargo-vessels, and shallow-draught steamers. Leaving out of account such items as reduction in first cost of machinery and gain in cargo space, taking

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the average i.h.p. of the improved designs at 2,500, and assuming that each ship steams for 240 days per year, using 1½ lb. of coal per i.h.p. per hour, and bunkers at 25s. per ton, the saving on each ship will be, it is reckoned, £700 per annum, or £10,500 per annum if only one ship of each of the 15 designs is built. The saving to the industry on one year's working of the tank would, therefore, cover the expenses of the establishment for some years to come, if maintained at about its present size. The Committee emphasise that the results are possible only because of the research work carried out in the past, and equally satisfactory results can only be achieved in the future by continuing research work.

Glasgow and West of Scotland Commercial College.

The enrolments during the session were about 2,000, a number greater than all previous records.

In several departments new developments were made; in particular, a successful appeal was made to retail distributors by the formation of a class on Salesmanship. The class on the Principles and Practice of Shipping continues to be well taken advantage of, as is also the class on German for technical students and works managers. A special class which had for its purpose the giving of general ideas regarding Book-keeping to works managers was also well attended.

The Governors have now definitely taken up their position with regard to the provision of a new building for the College, and a public appeal has been launched for a sum of £200,000. The inconvenience caused by lack of accommodation, with the consequent necessity to find class rooms in various parts of the city, had become so great that it was felt there should be no further delay in making this appeal. The preliminary response has been very gratifying, and it is hoped that in the near future Glasgow will be provided with a Commercial College worthy of the vast interests it has to serve.

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The Glasgow School of Art.

The number of students attending the School during the session was 1,099. Forty-four diplomas were granted, and ten students received endorsement on their diplomas for post-graduate work. A travelling scholarship of £120, four maintenance bursaries for next session value £66 each, and ten minor travelling bursaries to the value of £100 were awarded by the Governors, authorised by the Scottish Education Department, and the "John Keppie" scholarship of £100.

The continuation classes of the Education Authorities are affiliated to the School of Art, and the lending museum is now participated in by 80 schools.

Mr. John D. Revel, A.R.C.A., principal of the Chelsea School of Art, was appointed director, *vice* Mr. John Henderson, M.A., deceased, and took up duty on 2nd March, 1925. He was trained at the Royal College of Art, and holds the Art Masters' Certificate of the Board of Education.

An exhibition of brooches was held, which was of an educational character, and included interesting brooches of all periods lent by private individuals, and also a good exhibit of the work of modern artist craftsmen.

On 6th February, the School was honoured by a visit from the Secretary for Scotland, the Right Hon. Sir John Gilmour, Bart., accompanied by Mr. George Macdonald, C.B., LL.D., Secretary of the Scottish Education Department.

Royal Technical College.

The session was one of contrasts, brightened by the further evidence which the College received of public confidence in its work, darkened by depression in the great industries with which it is particularly associated.

Clyde engineering apprentices form the principal reservoir from which College students are drawn. Although there was a great reduction in the number of such apprentices, there was not a corresponding reduction in the number of

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College students of engineering, whose numbers still approach double those of pre-war years.

In the evening section there was a slight increase, instead of the decrease which might have been expected on account of the transfer of certain trades classes to the Education Authority.

The comparative figures for the two past sessions are as follows:—

	1923-24.	1924-25.
Day students - -	1,006	936
Evening students -	3,810	3,817
Totals - -	4,816	4,753

No fewer than six members of the College received the degree of Ph.D. from the University of Glasgow, and the degree of B.Sc. was conferred upon 59 students who had taken the whole or the major portion of their course in the College, and upon 36 other students who had also attended College classes. Twenty-four students were admitted to the Associateship of the College, and 41 were granted the College diploma.

The reorganisation of the Department of Mechanics and Mechanical Engineering, of which mention was made in the last report, has entailed considerable work during the past year in the rearrangement of classes and in the review and extension of the laboratory equipment. A start was made with a new laboratory to deal with problems in technical dynamics, for which an additional room was provided. A considerable enlargement of the resources for the testing of materials is in contemplation, and should greatly facilitate research on the difficult modern problems of materials. Especially to be noted in this connection is the new laboratory for investigating the heat treatment of steels, which was equipped during the session. There were installed four wire-wound electric resistance furnaces, capable of maintaining constant any temperature within the range of

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from 300 to 950 degrees C., with oil-quenching and water-quenching tanks placed beside the furnaces. The present intention is that two of the furnaces be kept at high temperatures for hardening, normalising, and annealing, the other two being used for tempering operations. In addition, there is a double-chamber furnace, with a blower for forced draught, for the hardening of high-speed steel.

Board of Trade Consultative Committee.

Owing to the existing depression in trade, fewer questions than usual came before the Committee.

The Committee recommended to shipbuilders that they should not submit to the transport officer general arrangement plans, cargo-capacity plans, and deadweight scales of vessels built by them without the consent of the owners.

It was reported that, owing to the continued efforts of the Shipbuilding Employers' Federation and Shipbuilders' Associations a reduction of 33⅓ per cent. in the fees payable by builders for tonnage measurement had been obtained.

Several questions arising out of the new instructions concerning the survey of lights and sound signals came before the Committee. They advised inquirers that the suggestions contained therein as to voltage of the electric supply to be used for navigation lights and other details were merely suggestions made by the Board, and were not compulsory.

There seemed to be some misapprehension among lamp-makers regarding the fees payable for testing samples of mast-head, side, and not-under-command lanterns, but the Committee pointed out that once a sample lantern had been approved by the Board, the maker could go on making and supplying lanterns of that approved pattern without payment of further fees.

During the year the Committee continued to press the Board for an indication of the date on which instructions applicable to home-trade vessels would be issued. The Board's reply was

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that no indication of this date could be given in the meantime, but that they would continue to deal on the merits of each case with the subdivision of home-trade vessels.

British Corporation Technical Committee.

The most important part of the work of the Committee during the past year was in connection with the completion of their revision of the Society's rules. New sections dealing with water-tube boilers, shafts, and tubes were added in the machinery rules, while the regulations governing the construction of hulls and their machinery, particularly of internal-combustion machinery, were revised so as to concur with the latest development in practice.

A large amount of experimental investigation was made, and continues to be made, in connection with the strength of ordinary mild steel, and that of special qualities, from which beneficial practical results are anticipated.

British Engineering Standards Association: Sectional Committee on Cast Iron.

The work of the Committee during the past year was mainly devoted to tabulating standard tests of materials which would conform to trade conditions. In this connection various specifications from the Admiralty, Railways, American Societies, Automobile Societies, etc., were carefully considered, and a standard specification was drawn up and submitted for general adoption.

British Engineering Standards Association: Sectional Committee on Machine Parts.

Screw Threads. The schedules of general dimensions of B.S.W. and B.S.F. bolts and nuts, which it was mentioned in last year's report had been issued as wall charts for workshop and drawing office use, have now in addition been

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published in octavo reports uniform with the other publications of the Association.

The standardisation of black cup head and countersunk bolts for railway wagon construction was undertaken at the request of the Railway Clearing House, and proposals, prepared by the manufacturers in conference with some of the leading wagon builders and the railway companies, were submitted to a Panel of the Association and provisionally approved for presentation to the Sub-Committee on Screw Threads. The proposals were circulated to the trade organisations interested for criticism. It is hoped that the standards will be found suitable for general constructional work when this type of bolt is used.

The revision of the standard dimensions of black hexagon nuts and bolt heads was undertaken, and a series of stock lengths similar to those incorporated in the reports on B.S.W. and B.S.F. bright bolts is being prepared.

The whole question of the width across flats, however, has been raised on the Continent and in America, and a meeting of the Sub-Committee on Screw Threads is being arranged with a view to considering whether any steps can be taken to reduce the width across flats for B.S.W. nuts and bolt heads, in view of the general trend on the Continent and America towards this end.

With regard to the question of wider tolerances for B.S.W. and B.S.F. bolts and nuts referred to in last year's report, an investigation into the errors prevalent on the screw threads supposed to be made in accordance with British Standards was put in hand, the Engineering Research Board of the Department of Scientific and Industrial Research having authorised its being undertaken by the National Physical Laboratory. A member of the staff of the laboratory personally visited a number of works and selected screws from stock for measurement, and samples were also forwarded by the Admiralty and the War Office.

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Keys and Keyways. Consideration of tables for taper keys, square and rectangular section, woodruff keys, and tangent keys is proceeding.

Driving Chains. The British standard specification for steel roller chains and chain wheels, Report No. 228—1925, was issued.

Spanners. The table of dimensions for British standard spanners, Report No. 192—1924, was published.

Ball Bearings. A draft specification for the dimensions and tolerances of ball and roller journal bearings and thrust bearings was circulated during the year to bodies interested, and a Sub-Committee of the B.E.S.A. is now actively engaged in preparing revised proposals in the light of the comments received.

British Engineering Standards Association: Sectional Committee on Petroleum Products.

During the past 12 months the following two publications have been issued:—

No. 209. British Standard Specification for Fuels for Heavy-Oil Engines (October, 1924).

No. 210. British Standard Classification of Pure Mineral Lubricating Oils (November, 1924).

The revision of the specification for benzol for motor fuel, which was referred to the Sub-Committee on Motor Spirit, proceeded to the extent that a specification for benzol for aircraft purposes was drawn up. The revision of the specification for benzol for ordinary motoring purposes was held up, pending further investigations being carried out by the National Benzol Association.

Samples of unbranded motor spirit (petrol) are now being collected, and these will be subjected to tests similar to those carried out about a year ago on samples of branded spirit. When the results of these tests become available, a meeting

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of the Sub-Committee on Motor Spirit will be held to consider whether any revision of the specification is necessary.

British Engineering Standards Association: Sub-Committee on Screw Threads.

The progress made by the Sub-Committee is referred to in the report of the Sectional Committee on Machine Parts.

British Engineering Standards Association: Sub-Committee on Steel Flanges for Hydraulic Pressure.

Since the formation of this Committee two years ago, five meetings have been held in London. The decisions arrived at so far are that hydraulic flanges shall be made of cast steel and drop forged steel. The shape and dimensions of flanges up to 2½ inches have been settled, while flanges of from 3 to 10 inches are still under consideration.

Institute of Metals: Corrosion Research Committee.

During the year the seventh Report of the Corrosion Research Committee was issued. While in some respects the research was fundamental in character, it is practically all definitely corelated to the problem of brass condenser-tube corrosion in marine installations. The phenomena of condenser-tube corrosion were analysed and classified, and a large number of protective factors investigated, but, speaking broadly, no general solution to the problem was found.

The Committee in the early part of the session appointed a new investigator, whose work was largely directed towards the investigation of protective coatings and research on the protective influence of ferric chloride and other iron compounds introduced as constituents of the circulating water. This work is still in progress.

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Institution of Civil Engineers: Committee on Tabulating the Results of Heat-Engine and Boiler Trials.

The chairman proposed that a general meeting be held early in 1926, say in January, at which the Committee's report might be presented, copies of it being submitted also to the Institutions and other bodies represented on the Committee; and that the report, whilst embodying all the Committee's work, should be of a provisional nature, and that wide publicity be given to it with a view to all interested in the contents being made aware of its publication. Suggestions as to improvements in the codes or notes would be invited, and after a period of six or eight months had elapsed the Committee would, say in the autumn of 1926, review any suggestions with a view to their incorporation in the Committee's final report, if that course appeared desirable.

Lloyd's Technical Committee.

The outstanding feature of the work of the Committee during the past year was the consideration of the proposed revised rules for vessels carrying oil in bulk. As is well known, practically all oil-carrying vessels built during the last 15 years have been constructed on the longitudinal system, and the successful experience gained with these vessels naturally formed the basis on which the revised rules were framed. These rules are interesting also from the fact that this is the first time an attempt has been made to frame a comprehensive set of scantlings based on the longitudinal system.

So far as the ordinary rules for the construction of ships are concerned, the work of the Committee was principally devoted to the consideration of the amendments to the scantlings of the framing, necessitated by the alteration to the framing formula suggested by the Committee of Technical Representatives of the Freeboard Assigning Authorities.

Careful consideration was also given by the Committee to

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the proposal to employ in shipbuilding special quality steel having a higher limit of proportionality than ordinary mild steel. As a result of their deliberations, tentative regulations for the testing of the new material were drawn up, and such material is being used in certain vessels now under construction.

The rules for electric fittings were revised in some respects. The principal amendment relates to the employment of higher voltages than previously allowed, for purposes other than the propulsion of ships. A new section was added to the rules concerning special requirements to be complied with when the constant-current series system is used.

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OBITUARY.

Members.

CHARLES ROSS BRUCE was born in Greenock on 4th May, 1874, and, after completing the usual course of education at the local academy, served his apprenticeship to marine engineering with Messrs. Scotts' Shipbuilding and Engineering Co., Ltd., Greenock. Apart from a few years spent elsewhere at the commencement of his career gaining experience, he spent the whole of his business life in Messrs. Scotts' service, rising from one position to another until in September, 1903, he was appointed chief of the estimating office.

Mr. Bruce was a man of high attainments and wide experience in engineering matters generally, but was particularly able in the department in which he specialised. He was the author of a small book, published a few years ago, entitled "Marine Engineering Estimates and Costs," which met with much acceptance. Keenly interested in all that pertained to the education and training of engineering apprentices, he taught with much ability and success for many years in the Greenock Technical School. He took a deep interest also in the affairs of the Greenock Association of Engineers and Shipbuilders, of which he was a past president, and with voice and pen did a great deal to further the progress of marine engineering. He died with startling suddenness at his residence in Greenock, on 7th March, 1926.

Mr. Bruce joined the Institution as a Member in 1904.

DAVID CRANSTON, born at Lanark on 10th November, 1848, died at Richmond, Yorkshire, on 12th February, 1926. Educated at Greenock Academy, he served his apprenticeship

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with Messrs. Scotts' Shipbuilding and Engineering Co., Ltd., Greenock, and afterwards spent twelve months in the works of the Fairfield Shipbuilding and Engineering Co., Govan, to gain experience. In 1872 he went to China, where he became closely identified with Messrs. S. C. Farnham, Boyd & Co., now known as the Shanghai Dock and Engineering Co., and was subsequently appointed a director of the company, from which he retired in 1907 and returned to Glasgow. During his retiral he took an active interest in the affairs of the Instituton.

Mr. Cranston joined the Institution as a Member in 1908.

WALTER DIXON was born at Hull in 1861, and acquired his early education in that city. He commenced his engineering career with Messrs. Amos & Smith, Hull, and after remaining with that firm for about ten years, joined Messrs. Richard Hornsby & Sons, Grantham, for whom he supervised many important contracts. In 1891 he came to Glasgow to join Mr. M. B. Mountain, who represented Messrs. Ernest Scott & Mountain, Newcastle, the Priestman oil engines, and other interests. Three years later he founded in Glasgow the firm of Walter Dixon & Co., electrical contractors, and carried out several schemes for the electrification of iron and steel works. At this stage he collaborated with the late Mr. James Riley in the early development of the gas engine for use in iron and steel works, and was among the pioneers in the introduction of three-phase alternating current for such works.

About 1903 Mr. Dixon relinquished his contracting business, and devoted his energies chiefly to consulting work. Among his other notable achievements may be mentioned the complete electrification of the properties of the Ebbw Vale Steel, Iron and Coal Co. During his association with that company, extending over a period of 20 years, the scheme grew from

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quite small dimensions to an installation consisting of three or four large power stations, with a total equipment of over 30,000 kilowatts. He was also responsible for the electrical equipment of the Rothesay Dock, Glasgow, the first dock in this country to be electrified completely. The scheme embodied many features not previously undertaken in any part of the world.

He was a past president of the West of Scotland Iron and Steel Institute, an active member of many technical and learned societies, and frequently contributed to their proceedings. He died at his home in Glasgow on 12th July, 1926.

Mr. Dixon joined the Institution as a Member in 1895.

GEORGE E. FLEMING, representative in Glasgow of Messrs. Dewrance & Co., passed away at Southgate, Middlesex, on 4th January, 1926. He was educated at Dollar Academy and at Manchester University, and served his apprenticeship as an engineer with Messrs. Mather & Platt, Ltd., Manchester. He afterwards entered the employment of Messrs. Dewrance & Co., in whose service he remained until his death.

Mr. Fleming joined the Institution as a Member in 1896.

DANIEL KEMP, engine works manager of Palmers Shipbuilding and Iron Co., Ltd., Jarrow, died suddenly on 16th May, 1926, at his residence at Monkseaton, Northumberland, at the age of 60 years. A native of Glasgow, he received his technical education at the Andersonian College in that city, and while there gained a Whitworth Scholarship. He served his apprenticeship to engineering in the works of Messrs. A. & P. Steven, and was afterwards connected with the Steel Co. of Scotland for a few years in their various works. Before joining Palmers Company 15 years ago, he held official posi-

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tions with Messrs. John Brown & Co., Ltd., Clydebank, and Messrs. Bow, McLachlan & Co., Ltd., Paisley.

Mr. Kemp joined the Institution as a Graduate in 1886, and was elected a Member in 1898.

ROBERT KENNEDY, Jun., died at Nairobi, Kenya Colony, on 22nd May, 1926. He was born at Glasgow on 10th March, 1883, and educated at Witney, Oxfordshire. Mr. Kennedy, who was trained as an engineer, and afterwards specialised in the manufacture of agricultural machinery, was for many years a director of Laurence Kennedy, Ltd., cow-milking machinery patentees and manufacturers, and was responsible for the organisation and development of the company throughout Australia, New Zealand, Canada, United States of America, and European countries. Subsequently he became a director of the Kennedy Motor Co., Ltd., and took an active interest in its commercial management.

Mr. Kennedy joined the Institution as a Member in 1922.

JOHN MCKENZIE was born in Stirlingshire on 8th August, 1852. Following his early training in Glasgow, he went to sea as an engineer in one of the State Line steamers, and on promotion to chief engineer sailed in that capacity with the same owners. After a brief connection with Messrs. Scotts' Shipbuilding and Engineering Co., Ltd., Greenock, and the London and Glasgow Shipbuilding and Engineering Co., Ltd., Govan, he became superintendent engineer to Messrs. James Gardiner & Co., shipowners, Glasgow, in which office he remained for over 30 years, retiring in 1916 when the firm sold their fleet. During the war he was engaged by the Ministry of Shipping on important shipbuilding and ship repairing work,

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and for a few years prior to his death, which took place on 28th January, 1926, he acted as a consulting engineer in Glasgow.

Mr. McKenzie joined the Institution as a Member in 1903.

JAMES HARPER MATHIESON, managing director of Messrs. A. Mathieson & Sons, Ltd., Saracen Tool Works, Glasgow, died at his home in Park Circus Place, Glasgow, on 15th April, 1926. Mr. Mathieson was a member of the Incorporation of Hammermen, and was elected Deacon-Convener of the Trades House in 1923. He took a worthy part in the civic life of Glasgow, and was a member of the Town Council from 1904 to 1910, being part of the time a Magistrate. He was also a Deputy-Lieutenant of the County.

Mr. Mathieson joined the Institution as a Member in 1901.

THOMAS MILLAR was born at Dunfermline on 9th March, 1858, and received his early education at the Public School, Kinghorn, this being supplemented later by technical training at the High School, Burntisland. He served his apprenticeship with Mr. John Key, engineer, Kinghorn, and later entered the drawing office as a draughtsman with Messrs. Harland & Wolff, Belfast. In 1880 he returned to Scotland to become chief draughtsman with Messrs John Key & Sons, of the Kirkcaldy Engine Works, where he remained for about two years. Subsequently he was appointed chief draughtsman at the Walker Shipyard of Messrs. Sir W. G. Armstrong & Co., and became assistant manager in 1888. Two years later he was made travelling representative of the firm, and in this capacity visited many countries arranging important contracts for ships of various kinds, including the Lake Baikal Ferry steamers, Russian and Finnish ice-breakers, and oil-tank steamers for service on the Caspian Sea. In 1905 he became

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a partner in the firm of Messrs. Gourlay Bros., Dundee, and two years later started business in Glasgow as a consulting engineer and naval architect, and as representative in Scotland of Messrs. Clarke, Chapman & Co. and the Darlington Forge Co. He died on 23rd December, 1925, at Kelvinside, Glasgow.

Mr. Millar joined the Institution as a Graduate in 1884, and was elected a Member in 1903.

Robert H. Moore was born at Gladsmuir, East Lothian, on 18th August, 1846, and died at his residence in Pollokshields, Glasgow, on 14th December, 1924, in his 79th year. Early in life he became an assistant to the late Dr. Alexander Kirk at the time he practised as a consulting engineer in Glasgow. Later Mr. Moore was appointed engineer at Blochairn Iron and Steel Works when it was started and carried on by Messrs. Schneider & Hannah. Subsequently he filled the post of manager at Messrs. William Beardmore & Co.'s Parkhead Works, and superintended the erection of the steel works there. For many years thereafter he was a partner in The Caledonian Steel Castings Co., Govan.

Mr. Moore joined the Institution as a Member in 1902.

Hugh Muir, born at Glasgow on 28th January, 1843, died there on 7th April, 1926. He was educated at Hutchesons' Grammar School, and served his apprenticeship with Messrs. D. & W. Napier. At the age of 21 he started business at the Scotia Engine Works in partnership with Mr. Caldwell. The firm was known as Muir & Caldwell, and specialised in steam steering gear. About 30 years ago Mr. Muir retired from active business, but maintained his interest in local affairs. He was for some time a director of the Western Infirmary, an ex-Deacon of the Incorporation of Hammermen, and assisted

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in promoting the welfare of the St. Andrew's Ambulance Association from its inception.

Mr. Muir joined the Institution as a Life Member in 1864.

JOHN STEVEN, founder of the firm of Steven & Struthers, brass founders and engineers, Kelvinhaugh, Glasgow, died at Fernlea, West Kilbride, on 4th January, 1926, in his 91st year. A native of Rutherglen, he started business with Mr. Struthers in 1866, and by his energy and skill made a great practical advancement in the use of gun metals and bronzes for various types of engines. Mr. Steven's knowledge of the mixing of alloys, combined with a thoroughly practical insight into the methods both of moulding and of casting these alloys, made his name familiar to all engineers. In the course of his business career, extending over 70 years, he came into close touch with many of the shipbuilders, engineers, and foundrymen who have made the West of Scotland famous throughout the world.

Mr. Steven joined the Institution as a Member in 1897, and took a keen interest in its welfare. He served as a Member of Council during sessions 1902 to 1905.

WILLIAM MAXWELL STEWART was born at Dalmuir on 31st January, 1875, and educated at Allan Glen's School, Glasgow, and the Glasgow University. He served his apprenticeship with Messrs. John Brown & Co., Ltd., Clydebank, and thereafter entered the service of Messrs. Clarke, Chapman & Co., Ltd., engineers and electrical machinery manufacturers, Gateshead-on-Tyne, as a draughtsman. After practising as a consulting electrical engineer, he became a director of Thermotank Co., Ltd., ventilating engineers, Glasgow. He died at Glasgow on 4th May, 1926.

Mr. Stewart joined the Institution as a Member in 1899.

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JAMES SYME commenced his engineering career in 1862 with Messrs. Randolph, Elder & Co., at their works in Centre Street, Tradeston, Glasgow. Shortly after the death of Mr. Elder in 1869, the firm changed its name to John Elder & Co., and continued so till 1885, when it became the Fairfield Shipbuilding and Engineering Co., Ltd. In 1863 the firm started shipbuilding at Govan, and three years later removed further down the river to Fairfield. The engineering side of the business continued at the old works in Centre Street until the new engine and boiler works were opened at Fairfield.

Throughout these successive changes Mr. Syme was associated with the company, and continued in active service at Fairfield until his retirement a few years ago. By merit he rose to the position of chief draughtsman, and was for a time engineering manager. He died at Partick on 25th December, 1925, aged 83 years.

Mr. Syme joined the Institution as a Member in 1877.

DAVID ROSS TODD was born at Glasgow on 31st October, 1860, and educated at Dennistoun Academy. He was apprenticed to Mr. John Steven, hydraulic engineer, Provanside Works, Glasgow, and afterwards gained experience in the construction of sugar machinery. He then joined the Fairfield Shipbuilding and Engineering Co., Ltd., Govan, and later became a draughtsman with Messrs. Babcock & Wilcox, Ltd., Renfrew. Subsequently he commenced business as a consulting engineer in Deansgate, Manchester, and patented a number of important improvements in water-tube boilers which were afterwards adopted by Messrs. Babcock & Wilcox. During the war he was appointed resident engineer of H.M. Factory at Langwith, where he did notable work. It was there that, after being badly gassed, his health broke down, and

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fettered a career of untiring energy and service. He died on 23rd October, 1925, at Deganwy, North Wales.

Mr. Todd joined the Institution as a Graduate in 1887, and was elected a Member in 1892.

Associate Member.

David Craig Simpson was born at Partick, Glasgow, on 27th January, 1883, and educated at Hamilton Crescent and Allan Glen's Schools. He served his apprenticeship as an engineer with Messrs. Crow, Harvey & Co., and was afterwards employed as a draughtsman with Messrs. James Bennie & Son, Cardonald, and later with the Central Drawing Office, Glasgow. He then joined Messrs. Norton & Gregory, Ltd., of London and Glasgow, and remained with that firm for about 20 years, the last five of which he was a director of the company. His death took place at Winston Avenue, Broomhill, Glasgow, on 25th May, 1925.

Mr. Simpson joined the Institution as an Associate Member in 1907.

Student.

Robert John Bell Dunn Rock was born in London on 10th October, 1900, and received his education in Glasgow. He served his apprenticeship with Messrs. Harland & Wolff, Ltd., and was afterwards trained as a cost and works accountant. He left Glasgow on 1st May, 1925, to take up an appointment with the African and Eastern Trade Corporation, Ltd., Bathurst, Gambia, British West Africa. He met his death by drowning on 11th October, 1925, while bathing at Cape St. Mary, Gambia.

Mr. Rock joined the Institution as a Student in 1925.

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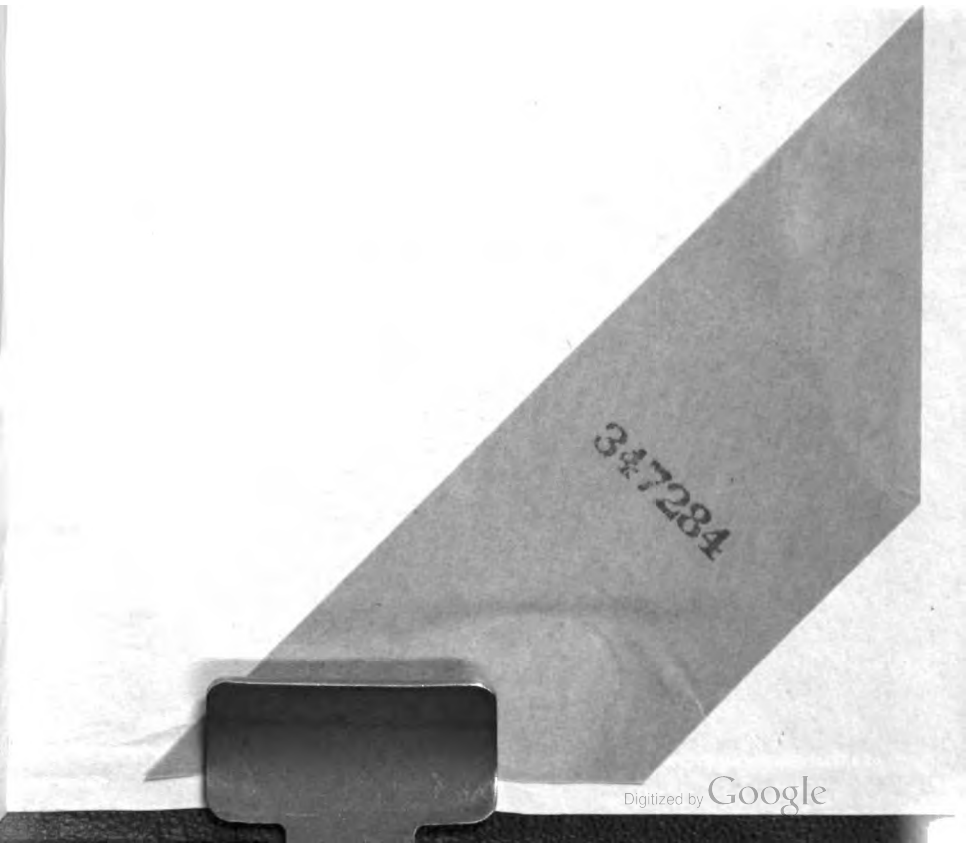
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